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FLAME TEMPERATURES AND INTERNAL
PRESSURES OF PYROTECHNIC
IGNITERS USED IN LIQUID
PROPELLANT GUN FIRINGS

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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ABERDEEN PROVING GROUND, MARYLAND

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Flame temperatures and internal pressures of various pyrotechnic igniters used in past NOS-365 bulk loaded liquid propellant gun (BLPG) firings were measured. The flame temperatures were measured using a modified line reversal method. The igniters were a radial venting type of primer and were selected for further study since these igniters, using the proper igniter element and booster charge, have yielded pressure time reproducibility firings superior to many of the earlier gun firings with NOS-365. (continued on reverse side)		

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The igniters consisted of either a T9E6 electric ignition element or an electric match element and a booster charge. The latter offered marginal ignition when fired in a BLPG. The former igniters provided adequate ignition and consisted of, in one case, a large M30 single perforated grain containing several strands of eimite and, in the other case, a Unique flake propellant. Average maximum measured flame temperatures were, respectively, 3060 K and 3280 K. The M30 plus eimite igniter gave a broader temperature curve than the Unique propellant. The pressure time curves revealed similar general characteristics as the temperature time curves, although more structure was evident with the temperature curves.

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I. INTRODUCTION

The lack of quantitative ignition design criteria in liquid propellant gun firings requires the development of appropriate diagnostics to study the igniter output. The initial energy distribution in the propellant during the ignition phase is one of the main unknowns during propellant ignition. Data on the initial energy distribution is required to understand fundamental mechanisms during liquid propellant ignition. A first step towards this goal is the measurement of the igniter output in terms of pressure, flame temperature and gas velocity. Past measurements on the output of pyrotechnic igniters consisted primarily of pressure data.^{1,2} To completely characterize the energy output of pyrotechnic igniters requires information on both the gas phase properties, i.e., the pressure, velocity and temperature distribution during venting and also on the particle properties during the multiphase flow. This paper addresses a diagnostic approach for measuring the igniter output, when venting at room conditions, in terms of flame temperature. Pressure time data obtained earlier using some of the same igniters are also included for comparison with the temperature data.

Bulk loaded liquid propellant gun firings have demonstrated the importance of the ignition phase as one of the critical elements necessary for achieving ballistic control.^{2,3} Two conditions are considered necessary: the igniter must be reproducible and must have the proper energy output characteristics to successfully ignite the propellant to

¹J. D. Knapton, I. C. Stobie and R. H. Comer, "Pyrotechnic Primer Design for Liquid Propellant Guns," 13th JANNAF Combustion Meeting, CPIA Publication No. 281, Vol. I, Applied Physics Laboratory, Silver Spring, p. 187 (1976).

²J. D. Knapton and I. C. Stobie, "Conditions Required for Controlling Breech Pressure During a Bulk Loaded Liquid Propellant Gun Firing (U)," 16th JANNAF Combustion Meeting, CPIA Publication No. 308, Vol. IV, Applied Physics Laboratory, Silver Spring, p. 51 (1979).

³J. D. Knapton and I. C. Stobie, "Bulk Loaded Liquid Propellant Guns: What Can be Expected in Terms of Pressure Reproducibility?", *Journal of Ballistics*, Vol. III, p. 615 (1980).

avoid pressure waves⁴ and, possibly, secondary ignition sites.^{2,5-7} The development of a pyrotechnic igniter to achieve these conditions has proven difficult. For example, an igniter using a T9E6 and a booster charge of Unique flake propellant yielded excellent reproducibility,^{1,8} yet the gun firings yielded a greater level of variability than a primer using a larger web propellant, containing M30 and eimite, but which had a lower level of reproducibility.⁹ It had been speculated that the igniter with the Unique flake booster charge yielded the relatively poor ballistic reproducibility due to an unnecessarily high rate of energy output which generated large pressure waves in the chamber and, possibly, uncontrolled ignition sites due to ignition at bubbles from adiabatic compression.^{2,5-7} On the other hand, the gun firings using the igniter with the M30 and eimite yielded breech pressure time traces with similar general features and a variation in the standard deviation of the peak breech pressure of 6.5%. This level of reproducibility is encouraging, especially when the

⁴ A. R. Guzdar, S. S. Rhee and A. J. Erickson, "Modeling Studies of the Liquid Propellant Gun," Foster-Miller Associates, Inc., Ballistic Research Laboratory Contract Report No. 57 (1971).

⁵ N. A. Messina, L. S. Ingram, Preston E. Camp, M. Ben Reuben and M. Summerfield, "Compression-Ignition Sensitivity Studies of Liquid Propellants for Guns," Princeton Combustion Research Laboratories, Inc., Report No. PCRL-FR-79-004 (1979).

⁶ V. M. Boyle and E. A. O'Leary, "Ignition of NOS-365 Liquid Propellant Containing an Air Bubble Under Simulated Breech Pressurization Conditions," USARRADCOM Technical Report ARBRL-TR-02236 (1980).

⁷ J. Mandzy, K. Schaefer, J. Knapton and W. Morrison, "Progress Report on Compression Ignition Sensitivity of NOS-365 Under Rapid Propellant Fill Conditions," 17th JANNAF Combustion Meeting, CPIA Publication No. 329, Vol. II, Applied Physics Laboratory, Silver Spring, Md., p. 309, (1980).

⁸ J. D. Knapton, I. C. Stobie and R. H. Comer, "Pyrotechnic Ignition Systems Used in a Medium Caliber Bulk Loaded Liquid Propellant Gun," 1978 JANNAF Propulsion Meeting, CPIA Publication No. 293, Vol. I, Applied Physics Laboratory, Silver Spring, p. 579 (1978).

⁹ J. D. Knapton, I. C. Stobie, R. H. Comer, B. Bensinger and D. Henry, "Results from a Study on the Ignition of Liquid Propellant Rounds in a Medium Caliber Gun Using a Radial Venting Primer," USARRADCOM Technical Report (being reviewed), 1982.

particular shape of the breech pressure time curve was associated with an increase in ballistic efficiency.¹⁰

Since past liquid propellant igniter studies have not been adequately characterized, it was considered that a study of the igniter temperature time output might aid in developing further empirical guidelines and assist in providing more general ignition requirements necessary for modeling the gun firings. Before describing the experimental details, a review of the relevant pyrotechnic systems used for ignition in past NOS-365 BLPG gun firings^{9,10} will be given.

II. PROCEDURE AND RESULTS

A. Pyrotechnic Igniters

The pyrotechnic igniter^{9,10} used in the tests is shown in Figure 1. Information on the properties of the ignition elements and the propellant used in the igniters is given in Appendix A. An electric igniter element (T9E6 or electric match) is discharged at the igniter base and together with a booster charge develops sufficient pressure to force a piston forward which uncovers holes in the wall of the igniter. Ideally, the piston displacement uncovers the holes simultaneously as well as integrating the early fluctuations in combustion. Two versions of the radially venting igniter were used. In one igniter, referred to as PR, the igniter consisted of a booster charge (usually M30 and eimite). In a later igniter, referred to as PRmx, the booster charge was changed to a Unique flake propellant and the components labeled "absorber" and "ignition element screen" were added as shown in Figure 1. The letter x refers to a particular modification and is 1 for a five hole venting igniter with a T9E6 element, 2 for three holes with a T9E6 element, and 6 for three holes with an electric match element.

B. Time Integrated Flame Output

Figures 2 and 3 show the time integrated flame output from some of the igniters taken using an open camera shutter and Polaroid Type 52 film with a camera setting of f/32. Figure 2a is an example of the output from an igniter that when fired in a gun resulted in an under ignited round with an abnormally long ignition delay.¹⁰ The igniter consisted of an electric match igniter element and 400 mg of Unique propellant. In the original photograph, the luminosity from the igniter

¹⁰ J.D. Knapton, I.C. Stobie, R.H. Comer, D. Henry, B. Bensinger and L. Stansbury, "Charge Design Studies for a Bulk Loaded Liquid Propellant Gun," USARRADCOM Technical Report ARBRL-TR-02127 (1978). (AD C017813L)

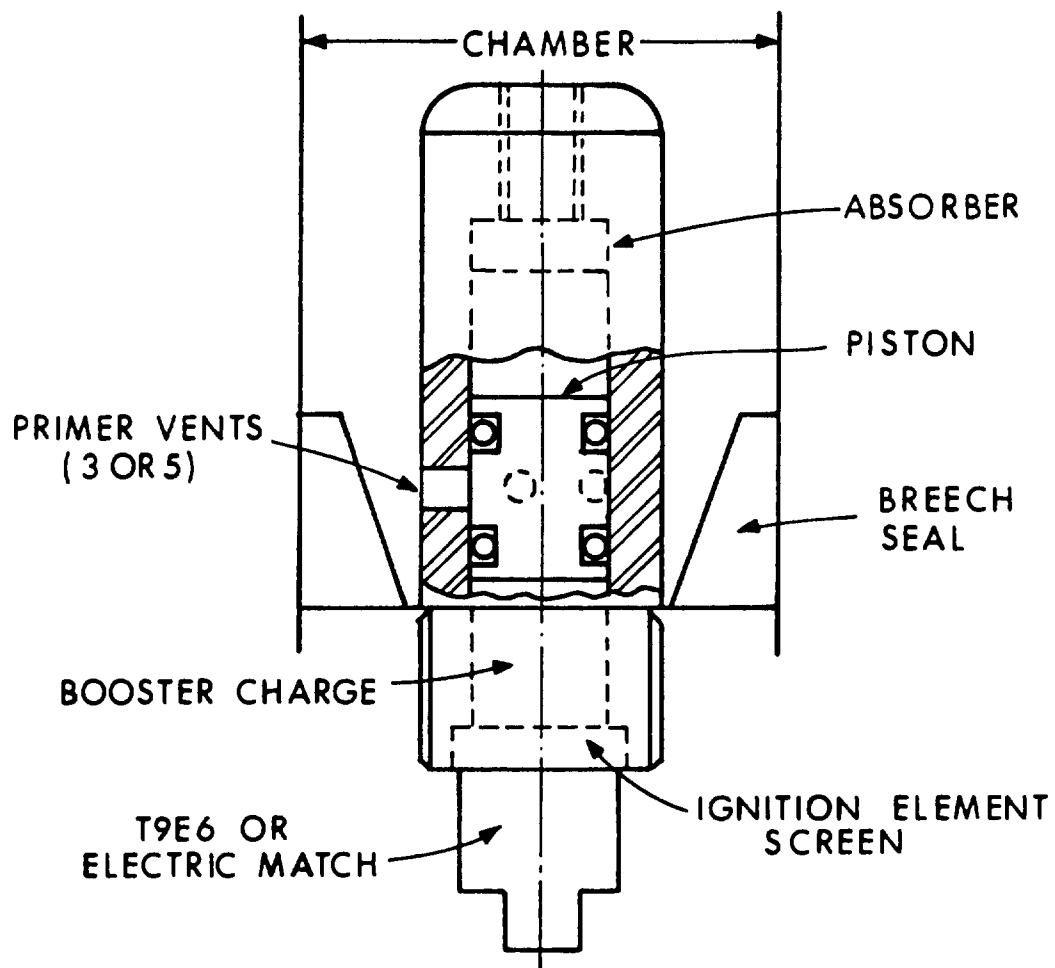
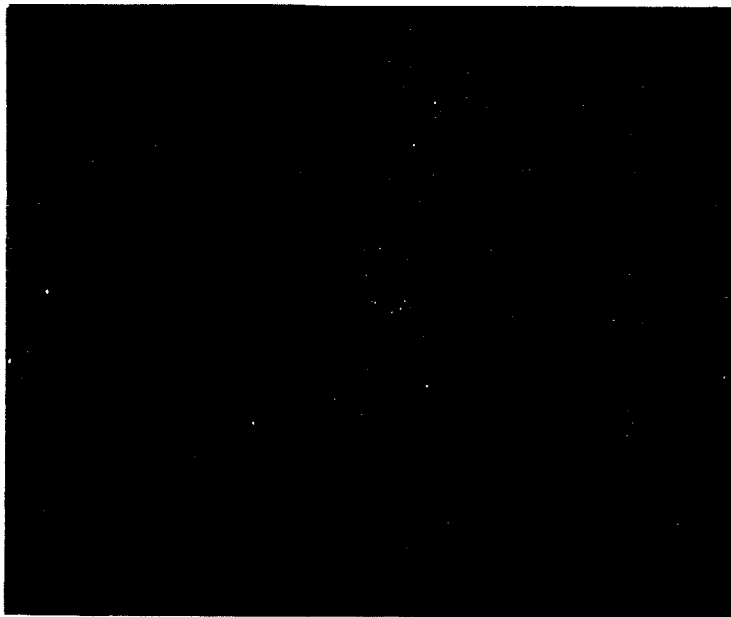
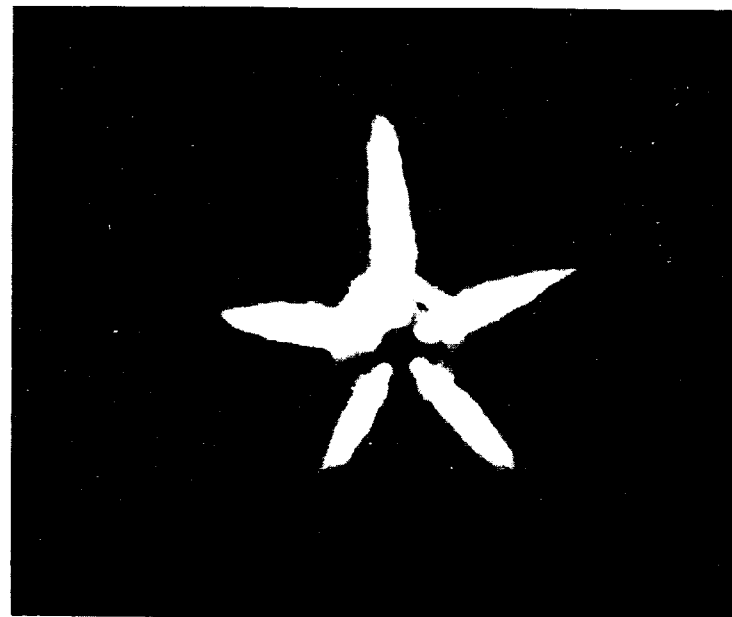


Figure 1. Schematic of Venting Primer



a) Igniter Type PR with Electric Match,
Unique and Piston

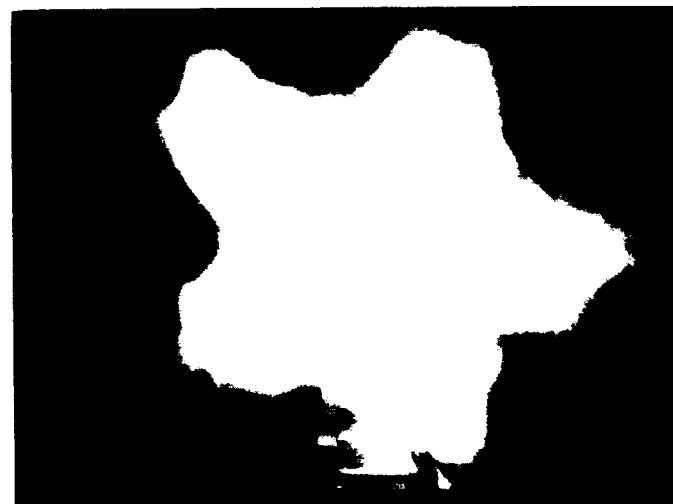


b) Igniter Type PR with Electric Match
and No Unique and No Piston

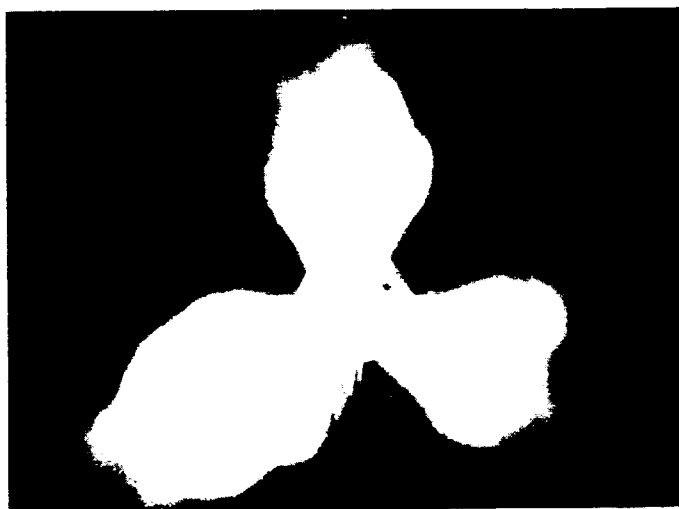
Figure 2. Time Integrated Pictures of Igniter Output



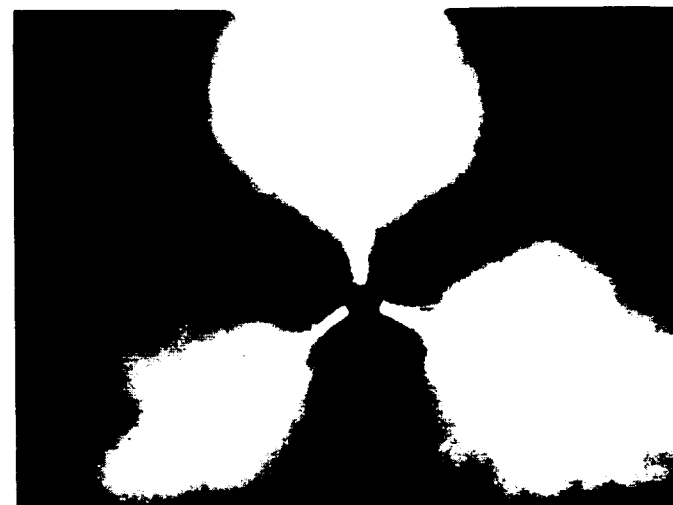
a) Igniter Type PR with M30 and Eimite



b) Igniter Type with No Booster Charge and No Piston



c) Igniter Type PRm2 with Piston But No Booster Charge



d) Igniter Type PRm2 with Unique and Piston

Figure 3. Time Integrated Pictures of Igniter Output. The electric igniter element in all cases was the T9E6.

vent holes is barely visible and the integrated output clearly does not demonstrate symmetric venting with only three holes (out of five) showing luminous output. Figure 2b shows the integrated output from the same igniter but without any Unique propellant and piston, Figure 2b was never used for gun firing as it was believed that the gas generated from the electric match would not be sufficient to displace the piston in a reproducible manner. Although Figure 2b without the piston suggests an improved level in venting symmetry, there is still evident venting asymmetry at the top vent hole and in the different lengths associated with the luminous jets.

Figure 3a illustrates the integrated output from the same igniter used in the tests shown in Figure 2, but with a T9E6 igniter element and with a booster charge of M30 and eimite. Symmetric venting clearly is not evident. For this case, however, the igniter output was sufficient to ignite the propellant in a gun chamber, whereas the igniter illustrated in Figure 2a would likely give an unacceptably long ignition time. For example, with a projectile shot start pressure of about 17 MPa, the time for combustion gases to generate 69 MPa was typically about 450 μ s (σ = 34%) using the igniter in Figure 3a, whereas the igniter shown in Figure 2a resulted in an inordinately long time (> 2 ms), along with considerable variability, to reach the same pressure level.¹⁰ Interestingly, although the igniter depicted in Figure 3a does not demonstrate symmetry during venting, the igniter did yield breech pressure time traces with the same general shape with a first peak pressure less than a second peak pressure. For a group of 12 firings in 38.8 mm BLPG¹⁰ the variation in the standard deviation for the maximum pressure was 6.5%.

Figures 3b, 3c, and 3d show an improved level of symmetric venting along with an increase in the integrated luminosity. Figures 3b and 3c were fired using only the T9E6 igniter element. No piston was used for the firing illustrated in Figure 3b. For the case with no piston, venting asymmetry is still evident by the "star bursts" and the luminous particle paths which do not directly originate at a primer vent. For the case where a piston was used, Figure 3c, the luminous particle paths falling outside of the symmetric vent patterns are eliminated, suggesting that the piston produces more burning within the primer and is effective in reducing the early fluctuations in combustion. No gun firings were made with this configuration, although the igniter would probably achieve propellant ignition when used in the same manner as the gun firings using the igniter shown in Figure 3a and based on some earlier gun firings made with an axially venting igniter using only the T9E6 igniter element.¹¹

¹¹W. F. McBratney, BRL, private communication.

Figure 3d shows the igniter output when the T9E6 is used to ignite a booster charge of Unique flake propellant. Luminous particles are visible and when compared with the igniter used in Figure 3c, are probably associated with the Unique propellant. Based on high speed photography of the venting, the igniter depicted in Figure 3d generated symmetric vent patterns to within 55 μ s. However, the pressure time traces from the gun firings when using this igniter produced over ignited rounds, typically generating a dominant first peak pressure.^{2,10}

C. Pressure Data

Pressure time data were obtained using an igniter modified as shown in Figure 4. A cylindrical cap was fitted over a PR type of igniter. The cap was drilled to give 3.45 mm diameter by 3.7 mm deep holes. The holes in the cylindrical cap were enlarged to provide pressure relief for the expanding gases. The smaller holes adjacent to the inner chamber retained the same length to diameter ratio (1.15) as the holes used in the actual igniter. The fifth hole in the cylindrical cap in Figure 4 was drilled to accomodate a Kistler 607B pressure gage. Obviously, the pressures measured with the modified igniter will not match the pressure of the actual igniter with hot gases venting from all five holes. However, a reasonable approximation of the pressure from an actual five hole venting primer could be obtained by modeling the pressure time characteristics using the experimental data to calibrate an appropriate model.

Several combinations of electrical igniters and booster charges were investigated. The results showing the pressure time records are given in Appendix B and a table summarizing the maximum pressure, pressure duration above 20.7 MPa, and the dominant pressure rise rate are tabulated in Table 1. The pressure level of 20.7 MPa was somewhat of an arbitrary selection; it represents a pressure level close to the first pressure transition of NOS-365¹². The dominant slope represents the maximum pressure rise rate and usually occurs between 40% to 90% of the maximum pressure. Values for the maximum pressure and the slope were determined by examining the analog visicorder records.

Figures B1 - B3 were obtained using a T9E6 igniter and a booster charge of M30 and eimite, Figures B4 - B9 were obtained using a T9E6 igniter and a booster charge of Unique, and Figures B10 - B11 were obtained using an electric match igniter and a booster charge of Unique.

¹²K. E. Travis, "Closed Chamber Burning Characteristics of Selected Liquid Monopropellants," 14th JANNAF Combustion Meeting, CPIA Publication No. 292, Vol. III, Applied Physics Laboratory, Silver Spring, MD, P. 1 (1977).

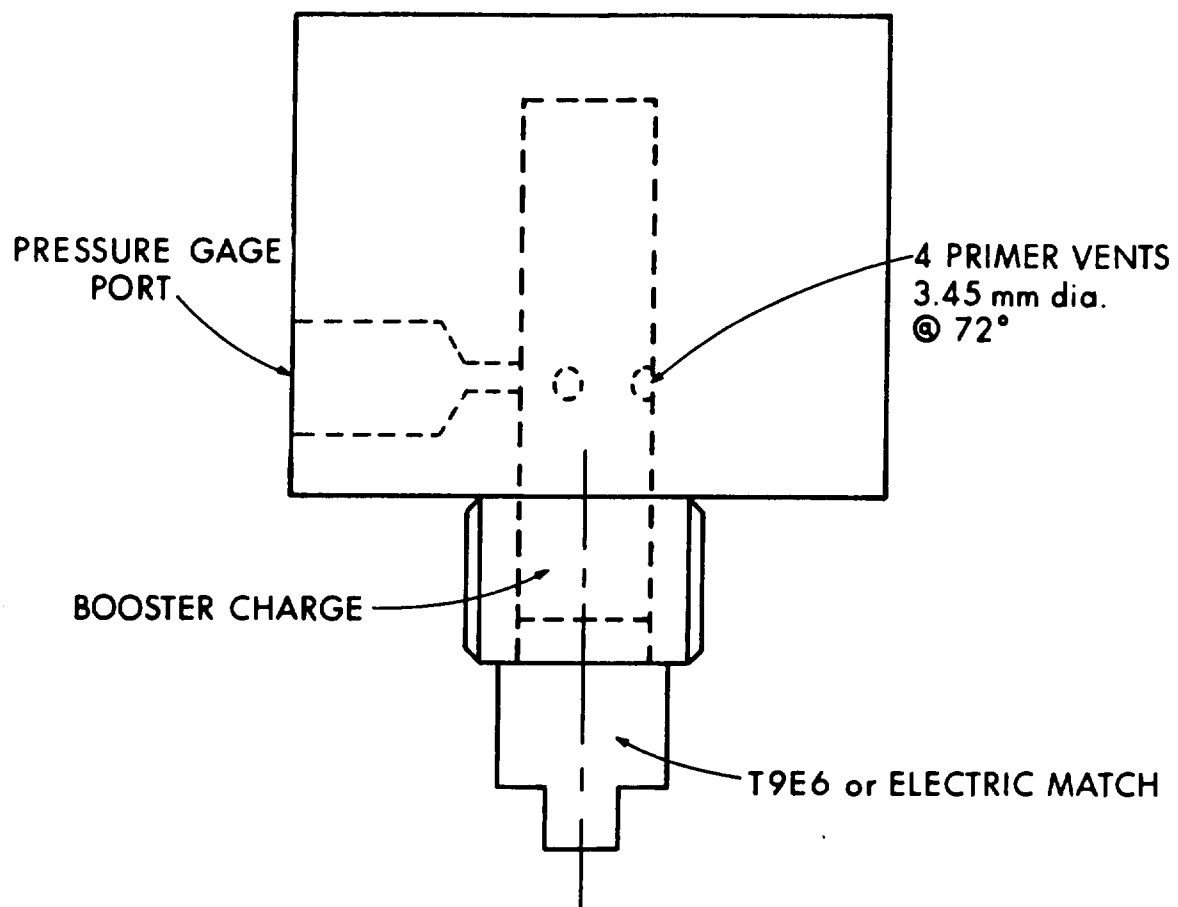


Figure 4. Primer Closed Chamber

TABLE 1. SUMMARY OF PRESSURE DATA OBTAINED FROM TESTS WITH THE PRIMER CHAMBER

Group	Ident. No.	Booster Charge				Max. Pressure (MPa)	Pressure Duration >20.7 MPa (ms)	Dominant Pressure Rise Rate (MPa/ms)
		Eimite No. of Sticks	Mass (mg)	M30 Mass (mg)	Unique Mass (mg)			
I	193-39	6	443	342	-	70.2	0.72	4070
	193-40	5	360	137	-	67.7	0.36	2760
	193-41	6	421	194	-	73.8	0.40	2254
II	211-57	-	-	-	230	87.9	0.24	3280
	211-58	-	-	-	230	77.9	.24	3570
III	211-59	-	-	-	330	93.2	.23	2900
	211-60	-	-	-	330	83.4	.26	1940
	211-61	-	-	-	330	64.2	.25	1500
	211-62	-	-	-	330	80.3	.38	1420
IV	230-34*	-	-	-	330	20.2	-	250
	230-35*	-	-	-	330	12.6	-	510

*Ignited using an electric match (Appendix A). The other firings were ignited using a T9E6 igniter (Appendix A).

A comparison of the results in Appendix B and Table 1 shows that despite the significant difference in the web and composition of the M30 and eimite booster charge (Group I) and the Unique booster charge (Groups II and III), there is a remarkable similarity in the overall shape of the pressure records. Presumably, the similarity is due to the dominance of the T9E6 igniter and attempts both to modify the combustion and to integrate the combustion fluctuations did not have a significant effect on the overall shape of the pressure time curve. This assumption is given further support by comparing the results between Groups II and III listed in Table 1. For Group II the booster charge consisted of 230 mg of Unique, while for Group III the booster charge was increased by 43%, yet the peak pressure and the pressure duration above 20.7 MPa did not change significantly. In fact the dominant rate of pressure rise actually decreased for the larger booster charge and is believed due to a larger concentration of unburned particles ejected from the igniter.

The features that are suggested when comparing the two different booster charge compositions, that is, the eimite and M30 (Group I) with the Unique (Groups II and III), are that the peak pressures for Group I are somewhat lower and the pressure durations >20.7 MPa for Group I are somewhat longer than the corresponding quantities observed for the Group II and III igniters.

The Groups I-III were ignited using the T9E6 igniter. In Group IV the booster charge was ignited using an electric match. Clearly, the decreased energy output from the electric match shows up as a significant decrease in maximum pressure and pressure rise rate even though the booster charge remained the same for Groups III and IV. Unburned booster charge was recovered from the igniter for the Group IV firings. As a result, the pressure did not go above 20.7 MPa.

A second series of firings were made in an attempt to increase the maximum pressure. Three neoprene buffers (dia. 11 mm, thickness 4.4 mm) were placed in the igniter cavity on the forward side of the piston. The purpose of the buffers was to produce an increased resistance to the piston's motion due to the compression of the buffers. The results are summarized in Table 2 and show that the buffers had the desired effect of increasing the maximum pressure. Although the uniformity in maximum pressure appears reasonable (standard deviation of 21%), there was considerable variability in the time to reach 20.7 MPa, varying by over a factor of ten.

D. Flame Emission

A diagram of the optical arrangement for recording the igniter flame emission is shown in Figure 5. A tungsten ribbon lamp rated at 30 A was used as a secondary standard. The lamp was connected to a constant current source supplying up to 40 A DC. The lamp was usually operated for the brief duration of the test at 37 to 38 A. Characteristics of the lamp are given in Appendix C. The filament was imaged approximately 3 to 5 mm above one of the igniter vent holes of a PRm2 or PRm6 igniter.

TABLE 2. SUMMARY OF PRESSURE DATA OBTAINED FROM TESTS WITH THE PRIMER CHAMBER. ALL TESTS WERE IGNITED USING AN ELECTRIC MATCH.

Group	Ident. No.	Booster Charge Unique Mass mg	Max. Pressure MPa	Time to 20.7 MPa ms	Pressure Duration > 20.7 MPa ms
V	230-49	400	36.8	0.7	.85
	230-51	400	55.2	.4	.88
	230-53	400	43.7	.33	.94
	230-54	400	41.4	.17	.83
	230-55	400	44.9	1.4	.95
	230-56	400	26.5	3.9	.50
	230-57	400	43.7	1.35	.88

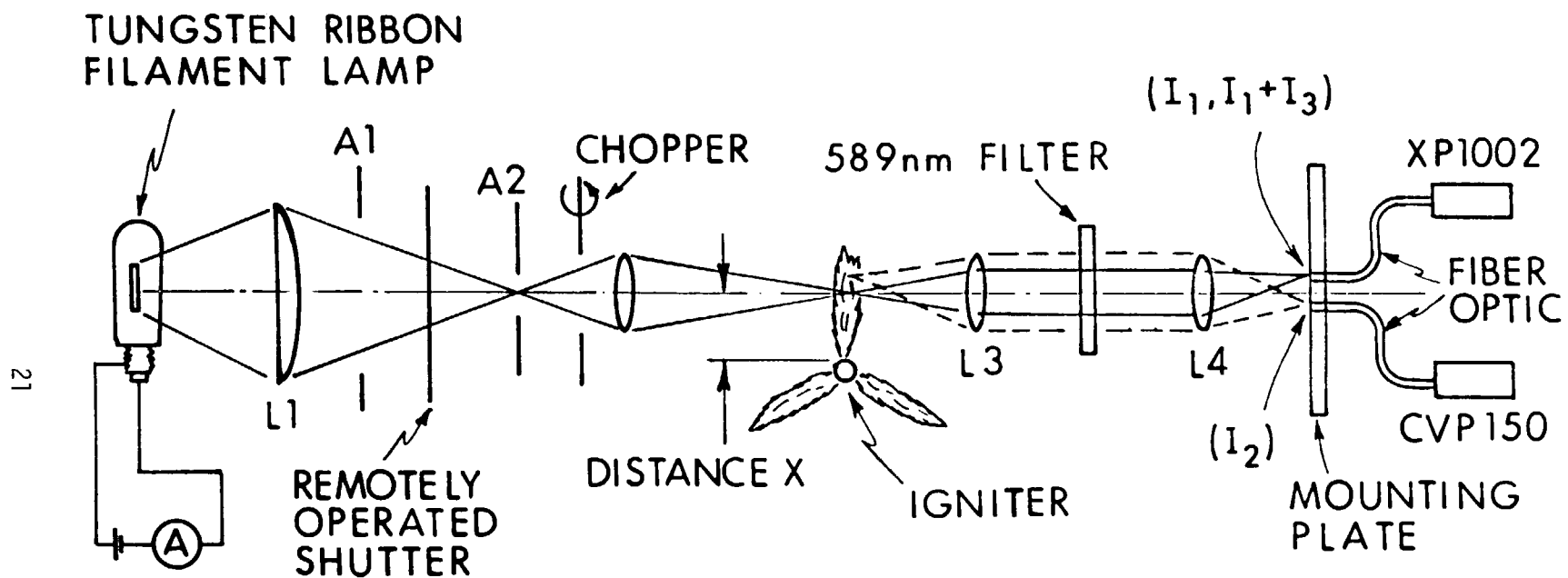


Figure 5. Optical Set-up for Studying Flame Emission and Line Reversal

The beam was then passed through a Na line filter and reimaged on the end of a 1.7 mm diameter fiber optic. The fiber optic transferred the image to a photomultiplier (XP1002). A second fiber optic mounted adjacent to the first fiber was used to transfer the light emitted from the flame to a second photomultiplier (CVP150).

Two different optical set-ups were tried and provided a basis for obtaining emission data at the 589 nm Na line and for estimating the flame temperature¹³ (following section). In one set-up, referred to as the chopped light method, a chopper was inserted into the reference beam as shown in Figure 5. For this method only one detector was used. In the second set-up, referred to as the two volume method, the chopper was removed and the relative intensities of two neighboring volumes in the igniter flame were measured.

1. Chopped Light Method. The chopped light method used only one detector (XP1002 at 1200 V) and thereby eliminated the need to match the response of the detectors. Three relative intensities were measured from the detector output:

I_1 = reference light prior to ignition

I_2 = emission of flame with chopper "closed"

I_3 = reference light plus flame emission with chopper "open".

The outputs from the detector are shown in Appendix D. Figures D1-D5 show the results of the first tests using the PRm2 igniter containing M30 and eimite. The chopper was operated at 1.7 kHz in Figure D1. In the next two tests, Figures D2 and D3, the frequency of the chopper was increased to its highest operating frequency of approximately 4.3 kHz. Important regions of the flame emission are masked by the rather low chopper frequency and the results can only be used as providing a rough indication of the flame emission.

2. Two Volume Method. The two volume method requires two detectors. The set up is shown in Figure 5 with the exception of the chopper which is not required for this method. One detector (XP1002, set at 900 V) monitored both the relative lamp intensity (I_1) prior to ignition and the relative lamp intensity plus flame emission (I_3) during the event. The second detector (CVP 150, set at 1350 V) monitored the flame emission (I_2). For this method a correction was made to account for the different sensitivities of the two photomultipliers. This was done by placing the reference lamp in the position of the event and illuminating equally the ends of the two fiber optics. The output voltages were monitored

¹³G. Klingenberg, K. J. White, J. D. Knapton, and W. F. Morrison, "Review of Spectroscopic Temperature Measurement Methods for Ballistic Applications," USARRADCOM Technical Report being reviewed (1932).

on an oscilloscope and were divided to obtain a correction factor which was applied arbitrarily to the output of the CVP 150 photomultiplier. The response from the XP1002 and the adjusted CVP 150 output was digitized using the BRL ballistic data acquisition system (BALDAS). The results are given in Appendix E.

It was found that the position of the fiber optics in the mounting plate (Figure 5) was very important for obtaining satisfactory results. A flush mount with the mounting plate was used for the tests. Also, it was found that a 0.3 neutral density filter was necessary when the booster charge consisted of Unique propellant. The neutral density filter was located on the flame side of the Na line filter.

E. Temperature Data

Temperature data was obtained using the two arrangements described in the previous section. For the method using the light chopper, a maximum true flame temperature T_f was calculated from¹³

$$\frac{1}{T_f} = \frac{1}{T_{\lambda 1}} + \frac{\lambda 1}{C_2} \ln \left[\left(1 - \frac{I_3 - I_1}{I_2} \right) \cdot \frac{1}{\tau} \right] \quad (1)$$

where $\lambda 1$ = peak wavelength transmitted by the filter

$$C_2 = 1.438 \text{ cm K}$$

τ = correction factor for the transmission of the imaging lens

$T_{\lambda 1}$ = brightness temperature of the tungsten calibration lamp at $\lambda 1$ (Appendix C).

$T_{\lambda 1}$ is given by

$$\frac{1}{T_{\lambda 1}} = \frac{1}{T_{\lambda 2}} + \frac{\lambda 2}{C_2} \ln \epsilon_{\lambda 2} - \frac{\lambda 1}{C_2} \ln \epsilon_{\lambda 1} + \frac{\lambda 2 - \lambda 1}{C_2} \ln \tau_{\beta} \quad (2)$$

where $T_{\lambda 2}$ = brightness temperature of the tungsten calibration lamp at $\lambda 2$ (usually 650 nm)

ϵ = emissivity of tungsten

τ_{β} = correction factor for the transmission of the window of the calibration lamp.

Based on earlier studies with a similar set-up by one of the authors (G. Klingenberg), values for τ and τ_p were set equal to 0.41 and 0.98.

1. Chopped Light Method. Values for I_1 , I_2 and I_3 were read directly from the BALDAS display. Eq. 1 was then used, after a value for $T_{\lambda 1}$ was found for Eq. 2, to calculate the maximum temperature. The results are summarized in Table 3.

2. Two Volume Method. Both photomultipliers were used and the chopper was removed. The digitized data from the response of the two photomultipliers, was operated on, in accordance with Eq. 1, using the BALDAS system to obtain the time dependent temperature plots shown in Appendix F. The maximum temperatures obtained by this method are compared in Table 3 with the maximum temperatures using the chopper method. Reasonable agreement is indicated in the table for the tests that are summarized. However, two tests using M30 and eimite as the booster charge yielded an abnormally low flame response. These tests with the abnormally low flame emission are not included in Table 3 since the difference in the response of the two photomultipliers was too large to yield a meaningful temperature. The reason for the abnormally low response from the flame for the two tests may have been due simply to the lack of symmetric venting (as suggested in Figure 3a), high particle content, or to poor alignment of the optical system.

III. DISCUSSION AND CONCLUSIONS

From Table 3 and the figures in Appendix F, it appears that the Unique booster charge gives a more intense temperature spike than the M30 and eimite booster charge. Also, the pressure time curves from the tests with the Unique are sharper and narrower than the tests with M30 and eimite. The tests with the Unique, as with the earlier experiments,^{8,9} were slightly more reproducible than the tests with the M30 and eimite. The average maximum temperatures were 3280 K and 3060 K for the test with Unique and M30 plus eimite.

The electric match data shows a long duration emission (Figure E5) over tens of milliseconds and maximum temperatures (Figure F5) about 1000 degrees less than the igniters used with the more successful gun firings.¹⁰ Clearly, the output from this particular type of igniter is not suited for the ignition of NOS-365 for bulk loaded gun tests.

The quantitative data from these tests can only be regarded as rough approximations. Significant errors may be introduced in the temperature calculations as a result of the approximation for τ and the fact that greatest accuracy is obtained from Eq. 1 when $T_f = T_{\lambda 1}$. For the conditions of the test $T_{\lambda 1}$ was 500 to 600 K less than the maximum calculated flame temperatures.

Despite the excellent reproducibility demonstrated in the earlier

TABLE 3. SUMMARY OF MAXIMUM IGNITER TEMPERATURES

Test No.	Igniter Booster Charge	Temperature Method	Maximum Temperature (K)
305-147	M30-eimite	Chopper	3040
305-152	M30-eimite	Chopper	3170
305-155	M30-eimite	Chopper	3090
305-155	M30-eimite	Two Volume	2955
305-162	Unique	Two Volume	3250
305-167	Unique	Two Volume	3330
305-168	Unique	Two Volume	3250

high speed photographic tests with the igniter containing the Unique booster charge, the data obtained from the present investigation clearly shows large variations in the time dependent luminosity and pressure. Whether further improvements in igniter reproducibility are possible and whether such improvements would lead to improved ballistic reproducibility is only speculative. However, based on the correlation between improvements in breech pressure reproducibility with the improvements in igniter reproducibility demonstrated in Ref. 3, we conclude that further improvements in ballistic control are possible.

A greater effort should be placed on the energy required for propellant ignition, if further studies on igniter systems are pursued. For example, the igniters used in the present study contained on the order of 10^3 J whereas it has been demonstrated that less than 1 J is sufficient for igniting the propellant.¹⁴ If the input energy can be reduced and at the same time generate an acceptable gas generation rate, then problems due to pressure waves and possible secondary ignition sites should be greatly reduced.

¹⁴J. D. Knapton, I. C. Stobie and K. E. Travis, "Liquid Propellant Characterization Tests at Maximum Loading Densities," 1979 JANNAF Propulsion Meeting, CPIA Publication No. 300, Vol. I, Applied Physics Laboratory, Silver Spring, MD, p. 393 (1979).

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1. J. D. Knapton, I. C. Stobie and R. H. Comer, "Pyrotechnic Primer Design for Liquid Propellant Guns," 13th JANNAF Combustion Meeting, CPIA Publication No. 281, Vol. I, Applied Physics Laboratory, Silver Spring, MD, p. 187 (1976).
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7. J. Mandzy, K. Schaefer, J. Knapton and W. Morrison, "Progress Report on Compression Ignition Sensitivity of NOS-365 Under Rapid Propellant Fill Conditions," 17th JANNAF Combustion Meeting, CPIA Publication No. 329, Vol. II, Applied Physics Laboratory, Silver Spring, Md., p. 309, (1980).
8. J. D. Knapton, I.C. Stobie and R. H. Comer, "Pyrotechnic Ignition Systems Used in a Medium Caliber Bulk Loaded Liquid Propellant Gun," 1978 JANNAF Propulsion Meeting, CPIA Publication No. 293, Vol. I, Applied Physics Laboratory, Silver Spring, p. 579 (1978).
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11. W. F. McBratney, BRL, private communication.

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13. G. Klingenberg, K. J. White, J. D. Knapton, and W. F. Morrison, "Review of Spectroscopic Temperature Measurement Methods for Ballistic Applications," USARRADCOM Technical Report being reviewed (1982).
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APPENDIX A

IGNITER ELEMENTS AND BOOSTER CHARGES USED IN THE PYROTECHNIC IGNITERS

TABLE A-1. PROPERTIES OF M103/M203 ELECTRIC MATCH

A-1 Electric Match. The electric matches selected for the study were manufactured by Atlas Chemical Industries, Inc.^{A-1} and were designated M103/M203. Physical dimensions of the match head, electrical resistance and chemical composition were taken from Ref. A-1 and are summarized in Table A-1. Total combustible mass is approximately 25 mg based on weighings before and after firings.^{A-2}

Head Dimensions			Resistance	"All Fire" Conditions	Head Composition				
Width	Length	Thick- ness			1st Coat	2nd Coat	3rd Coat	4th Coat	5th Coat
mm	mm	mm	ohm						
4.0±	4.8±	2.8±	1.2 to 1.4	0.50A for	(a)	(a)	(b)	(c)	(c)
0.8	1.5	0.8		50 ms					

(a) 76.5% Lead Mononitrorescorbate
8.5% Potassium Chlorate
15.0% 1/2 Sec. Nitrocotton, in Iso-Amyl Acetate

(b) 51.0% Cerium Magnesium
40.5% Lead Peroxide
6.5% Aluminum (Alcoa #606 Standard unpolished)
2.0% Darco X

(c) 6 oz 376 Sec. Nitrocotton
1 gal Ethyl Ether (2 parts by vol.)
Ethyl Alcohol (1 part by vol.)

^{A-1} Data Sheet 420, 5-70, Atlas Chemical Industries, Inc., Aerospace Components Division, Valley Forge, PA 19481.

^{A-2} R. E. Bowman, Applied Physics Branch, BRL, 1980.

TABLE A-2. T9E6 ELECTRIC IGNITION ELEMENT

Table A-2. Composition of the T9E6 Electric Ignition Element

Barium Nitrate, class 1	20%
Lead Dioxide, grade A	20%
PETN	20%
Zirconium (granular)	32.5%
Zirconium, 120 grade	7.5%
Weight: 4.40 - .80 grains = .286 - .052 gms	
Volume of ignition element cavity	.22 cm ³
(Measured after firing)	
Volume of booster cavity	2.1 cm ³
Firing Voltage used in tests: 366 volts	
Label: T9E6 Ignition Element	
DA-28-017-501-ORD-3865	
Olin-Mathieson Chemical Corp.	
Lot WCC 1-3, Date: 8-60	

TABLE A-3. PROPERTIES OF THE BOOSTER CHARGES USED IN THE
RADIALLY VENTING PYROTECHNIC PRIMERS

<u>Ref</u>	<u>Propellant</u>	<u>Flame Temp, K</u>	<u>Force J/kgx10⁶</u>	<u>Form Used in Igniter</u>
A-3	Hercules Unique	3650	1.14	disc, 1.5 mm diameter
A-3 A-5	Eimite	2590	0.53	strand, 2 mm dia; 15 mm long
A-4	M30	3040	1.09	disc, 11 mm OD, 6.4 mm ID; 3.5 mm thick

COMPOSITION

Hercules Unique - 30% NG; 68% NC; 1.15% EC, Stabilizer; .75% K₂SO₄

Eimite - 40% NC; 27.6% KNO₃; 16.7% Mg; 9.8% S; 5.9% Resorcinol

M30 - 27.97% NC; 22.48% NG; 0.1% Graphite; 1.5 Et Centralite; 1.0% K₂SO₄
47.65% NGU

A-3 *Private communication from Bert Grollman, Ballistic Research Laboratory, June 76.*

A-4 *L. Stansbury and A. J. Budka, "A Mathematical Model for Design-Evaluation of Vented Ammunition Boxes," BRL MR 2590, Feb 76. (AD B009785L)*

A-5 *Private communication from E. Freedman, Ballistic Research Laboratory, Dec. 1981.*

APPENDIX B
PRESSURE TIME DATA

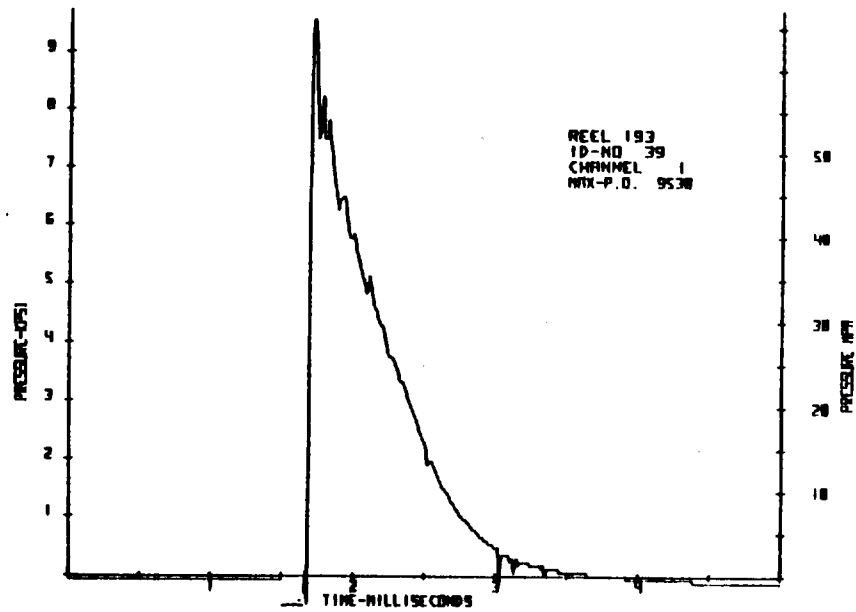


Figure B1. T9E6 Igniter and a Booster Charge of M30 and Eimite

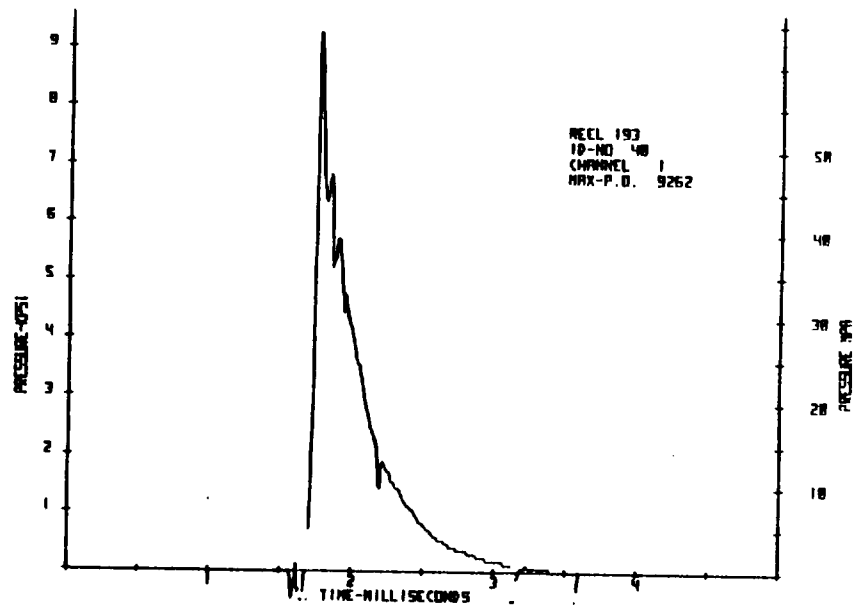


Figure B2. T9E6 Igniter and a Booster Charge of M30 and Eimite

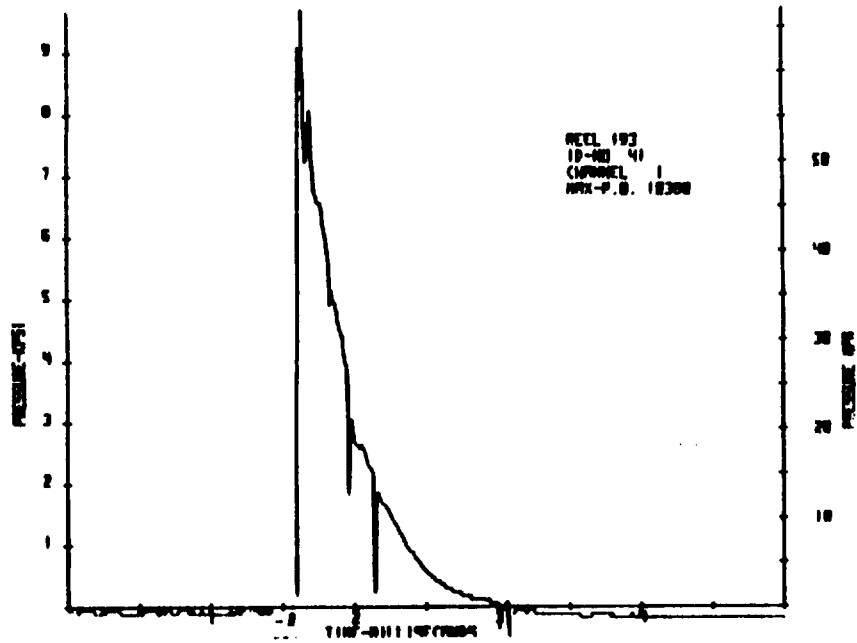


Figure B3. T9E6 Igniter and a Booster Charge of M30 and Eimite

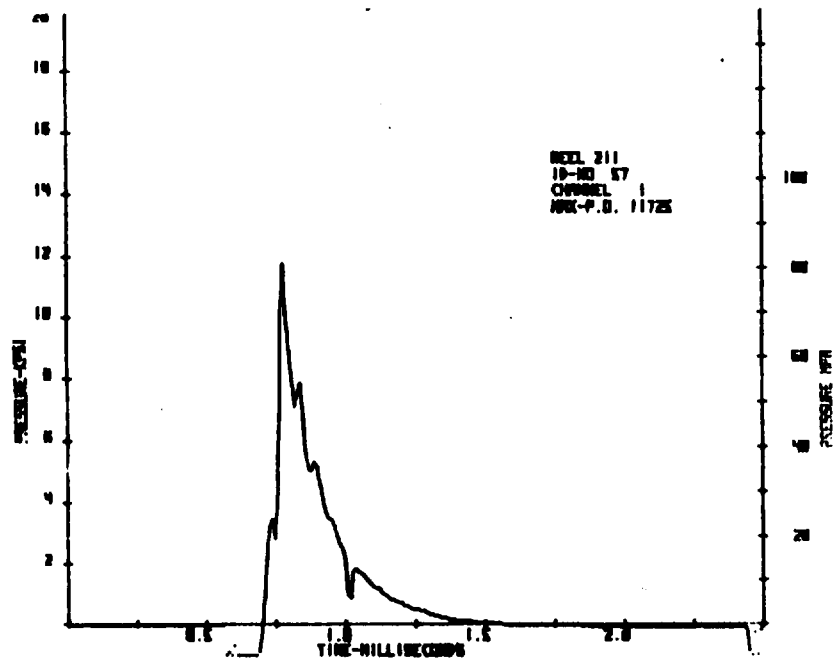


Figure B4. T9E6 Igniter and a Booster Charge of Unique

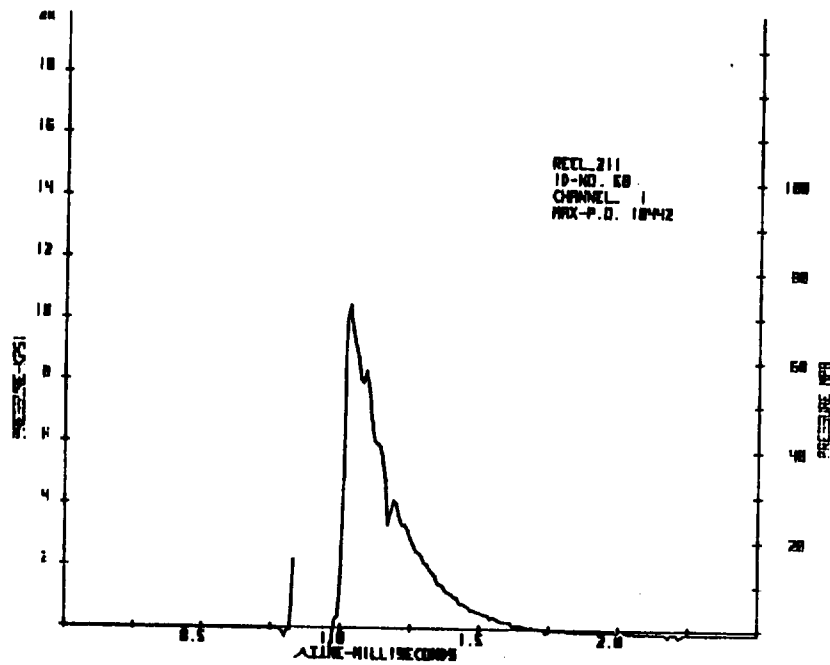


Figure B5. T9E6 Igniter and a Booster Charge of Unique

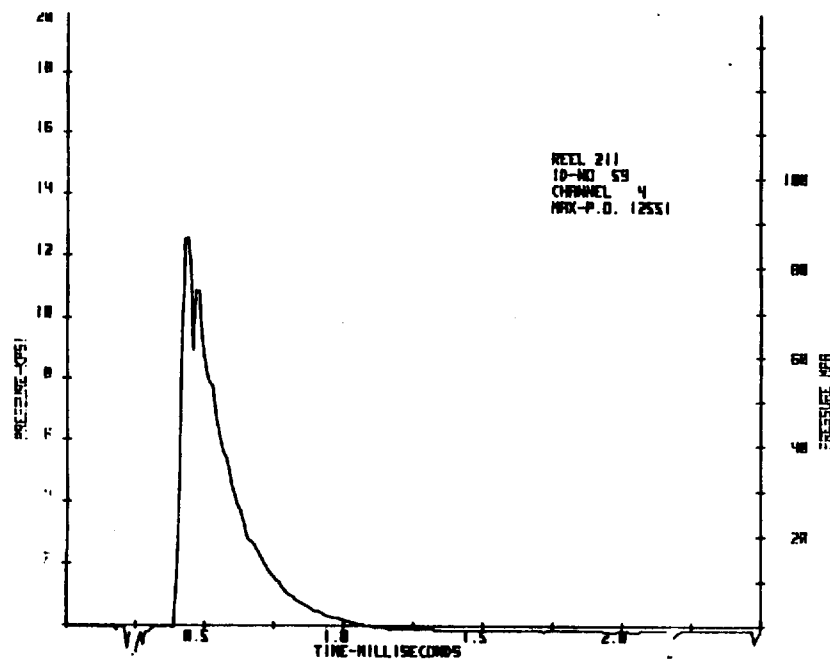


Figure B6. T9E6 Igniter and a Booster Charge of Unique

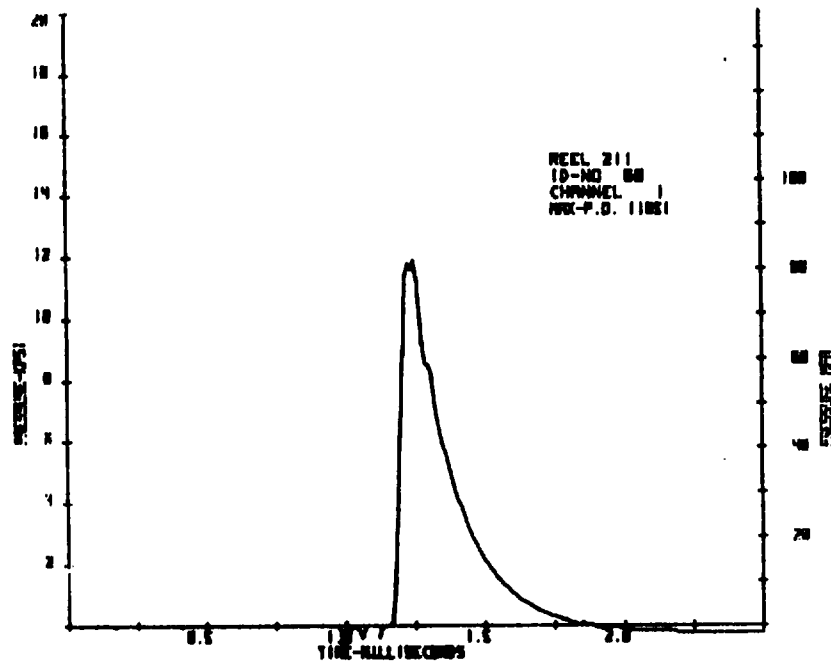


Figure B7. T9E6 Igniter and a Booster Charge of Unique

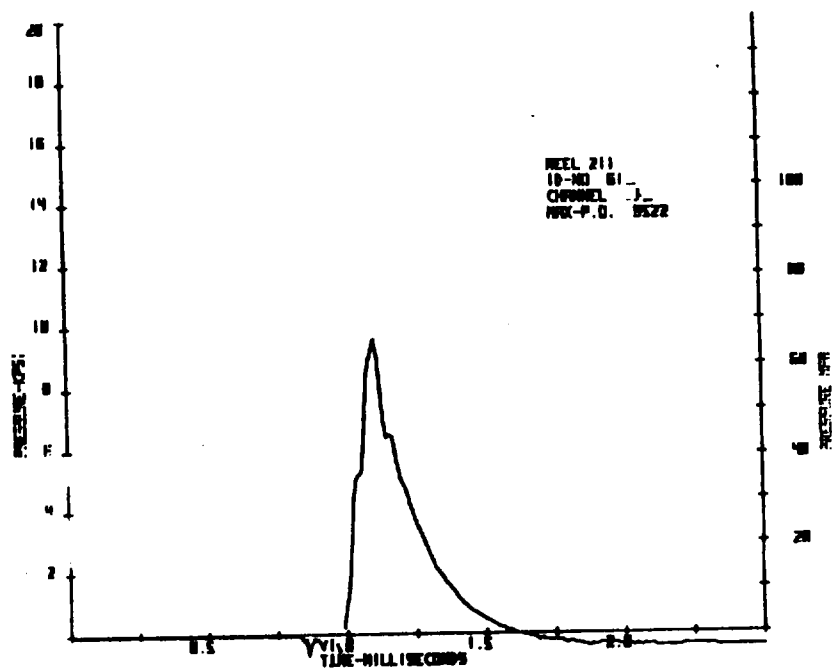


Figure B8. T9E6 Igniter and a Booster Charge of Unique

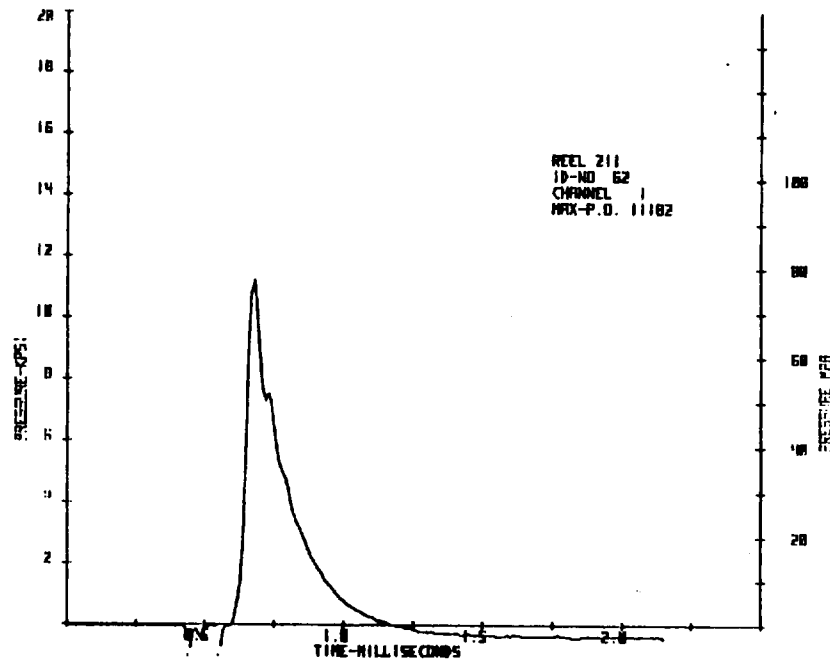


Figure B9. T9E6 Igniter and a Booster Charge of Unique

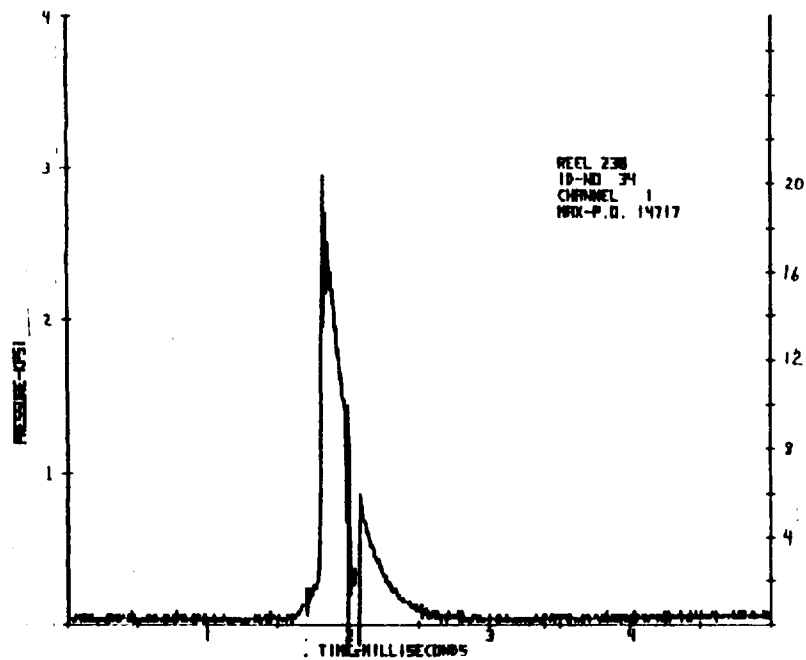


Figure B10. Electric Match Igniter and a Booster Charge of Unique

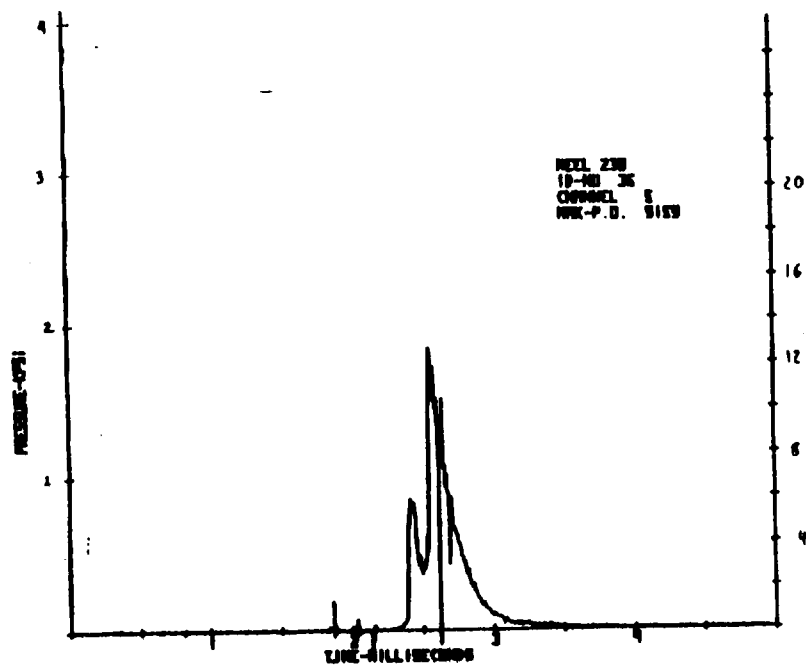


Figure B11. Electric Match Igniter and a Booster Charge of Unique

APPENDIX C

CHARACTERISTICS OF THE TUNGSTEN RIBBON FILAMENT LAMP

A ribbon filament lamp with a Pyrex envelop was calibrated at the NBS in terms of brightness temperature (T_s) at 655 nm vs lamp current. The calibration data is given in the first two columns in Table C-1. To obtain the true temperature (T) of the filament, the emissivity (ϵ) of the tungsten must be known which requires a value for T . T can first be estimated by simply referring to a nomogram in Reference C-1. (In the nomogram T_s was determined at 645 nm. Differences in ϵ between 645 nm and the 655 nm used for calibrating the lamp are insignificant for purposes of estimating T). With a first estimate for T , values for ϵ may then be obtained from the data of deVos^{C-2} at 645 nm. A second estimate of T can now be made using the value for ϵ and the equation^{C-3}

$$\frac{1}{T} = \frac{1}{T_s} + \frac{\lambda}{C_2} \ln \epsilon \quad (C1)$$

where λ = wavelength

$$C_2 = 1.4380 \text{ cm K.}$$

The second estimate of T_1 referred to as T_1 in the table, differs from the first estimate of T by about 1% at the higher temperatures. Further iterations on ϵ and T are not necessary since subsequent changes in T , after selecting a revised ϵ , are only one degree or less. A plot of T_s and T_1 vs I is given in Figure C1.

^{C-1}F. Rossler, "Temperaturmessungen in Kurzzeitphysik," edited by Vollruth and Thomer, Springer, Wein (1967).

^{C-2}J. deVos, "A New Determination of the Emissivity of Tungsten Ribbon," *Physica* 20, 690 (1954).

^{C-3}G. Klingenberg, K. J. White and J. D. Knapton and W. F. Morrison, "Review of Spectroscopic Temperature Measurement Methods for Ballistic Applications," USARRADCOM Technical Report being reviewed (1981).

TABLE C-1. CHARACTERISTICS OF THE TUNGSTEN RIBBON
FILAMENT LAMP AT 655 NM.

I^a	T_s^a	T^b	ϵ^c	T_l^d
(A)	(K)	(K)		(K)
11.34	1073	1125		
12.19	1173	1233		
13.23	1273	1345	0.4552	1333
14.47	1373	1453	.4528	1443
15.92	1473	1568	.4507	1555
17.58	1573	1682	.4483	1667
19.41	1673	1795	.4460	1781
21.39	1773	1912	.4438	1895
23.51	1873	2029	.4417	2011
25.74	1973	2148	.4394	2128
28.08	2073	2268	.4373	2246
30.52	2173	2390	.4350	2365
33.05	2273	2522	.4327	2485
35.68	2373	2635	.4303	2607
38.41	2473	2760	.4281	2730
41.24	2573	2890	.4257	2854

- a. National Bureau of Standards Report of Calibration, Test No. 534/G-43760A, August 6, 1979.
- b. Numbers read from nomogram, Ref. C-1.
- c. Numbers extrapolated from plot in Ref. C-2.
- d. Calculated using Eq. C1 and values for ϵ .

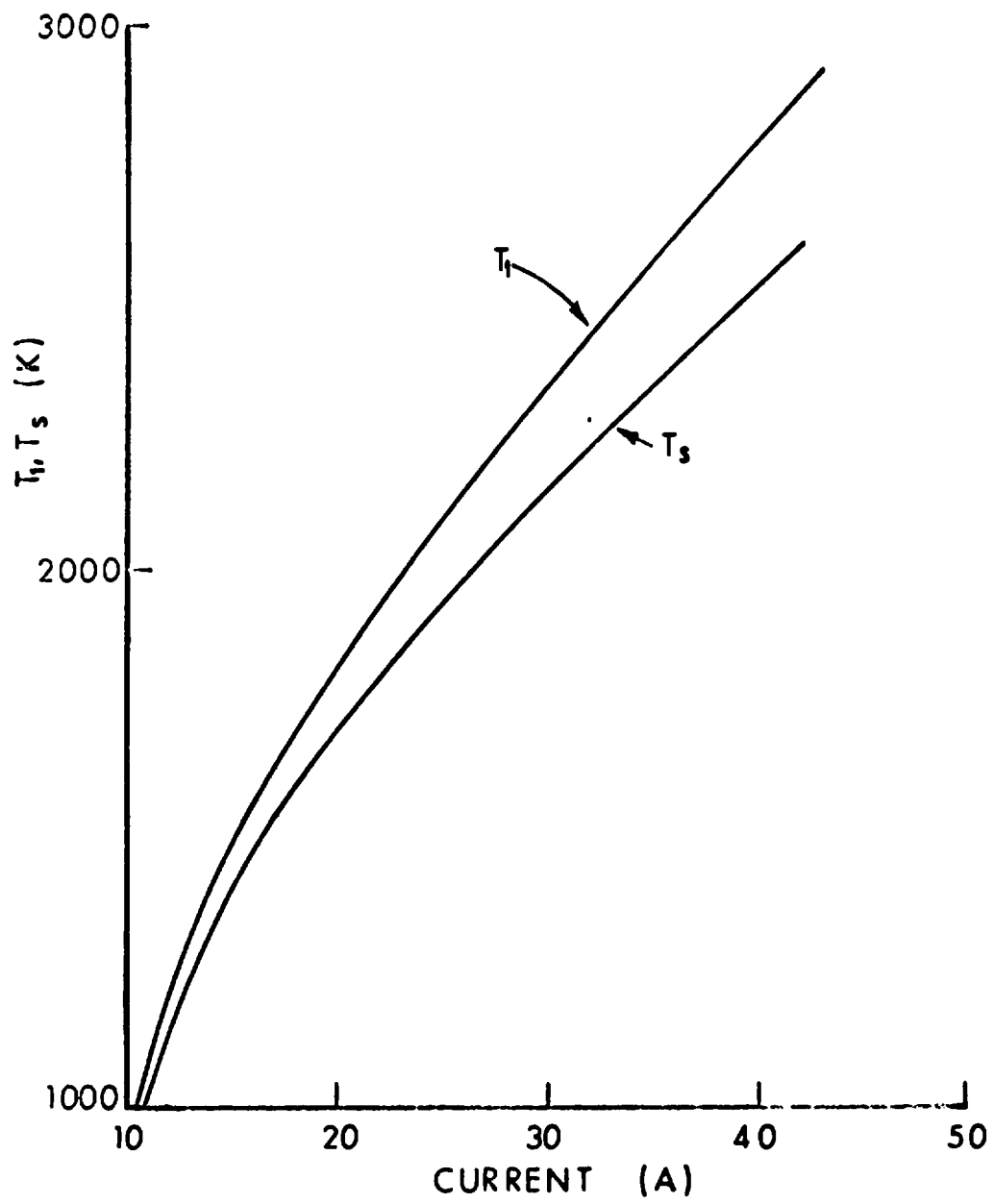


Figure C1. Plot of T_s and T_1 vs Lamp Current

APPENDIX D

EMISSION TIME DATA. CHOPPED LIGHT METHOD

IGNITER FIRING

ROUND: 147

45

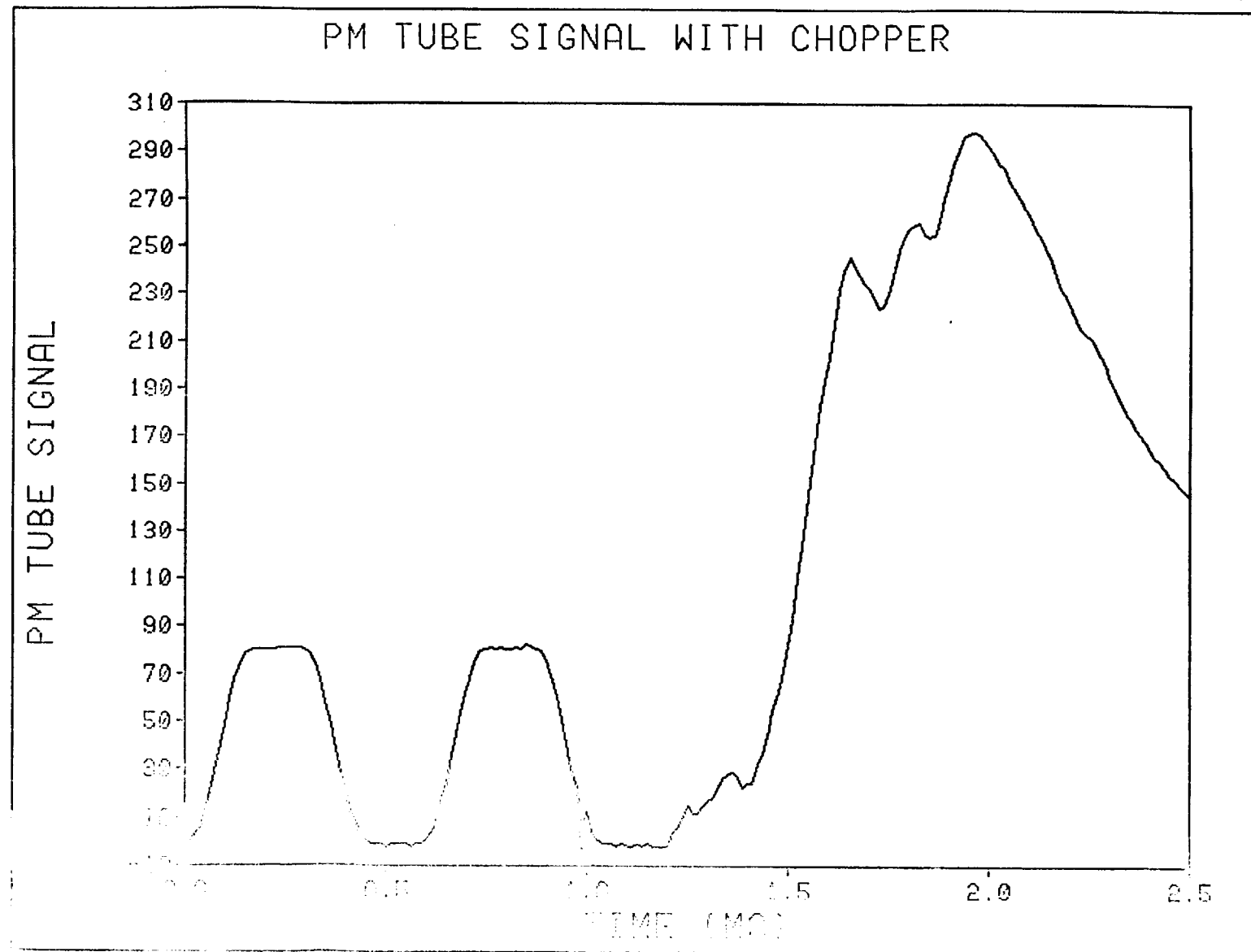


Figure D-1. Round 147 - Photomultiplier Tube Signal with Chopper

ROUND: 152

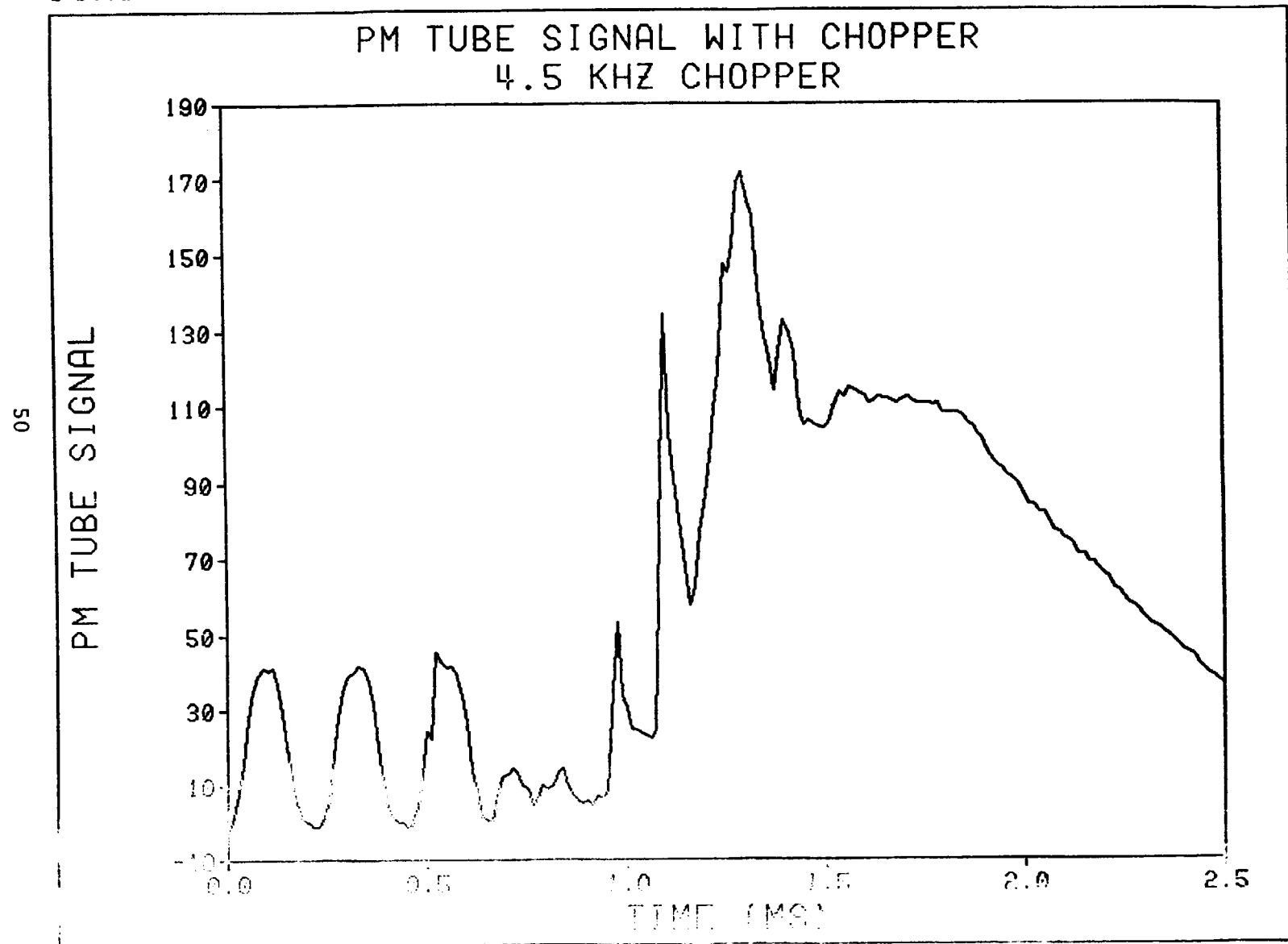


Figure D-2. Round 152 - Photomultiplier Tube Signal with Chopper, 4.5 kHz Chopper

IGNITER FIRING

ROUND: 153

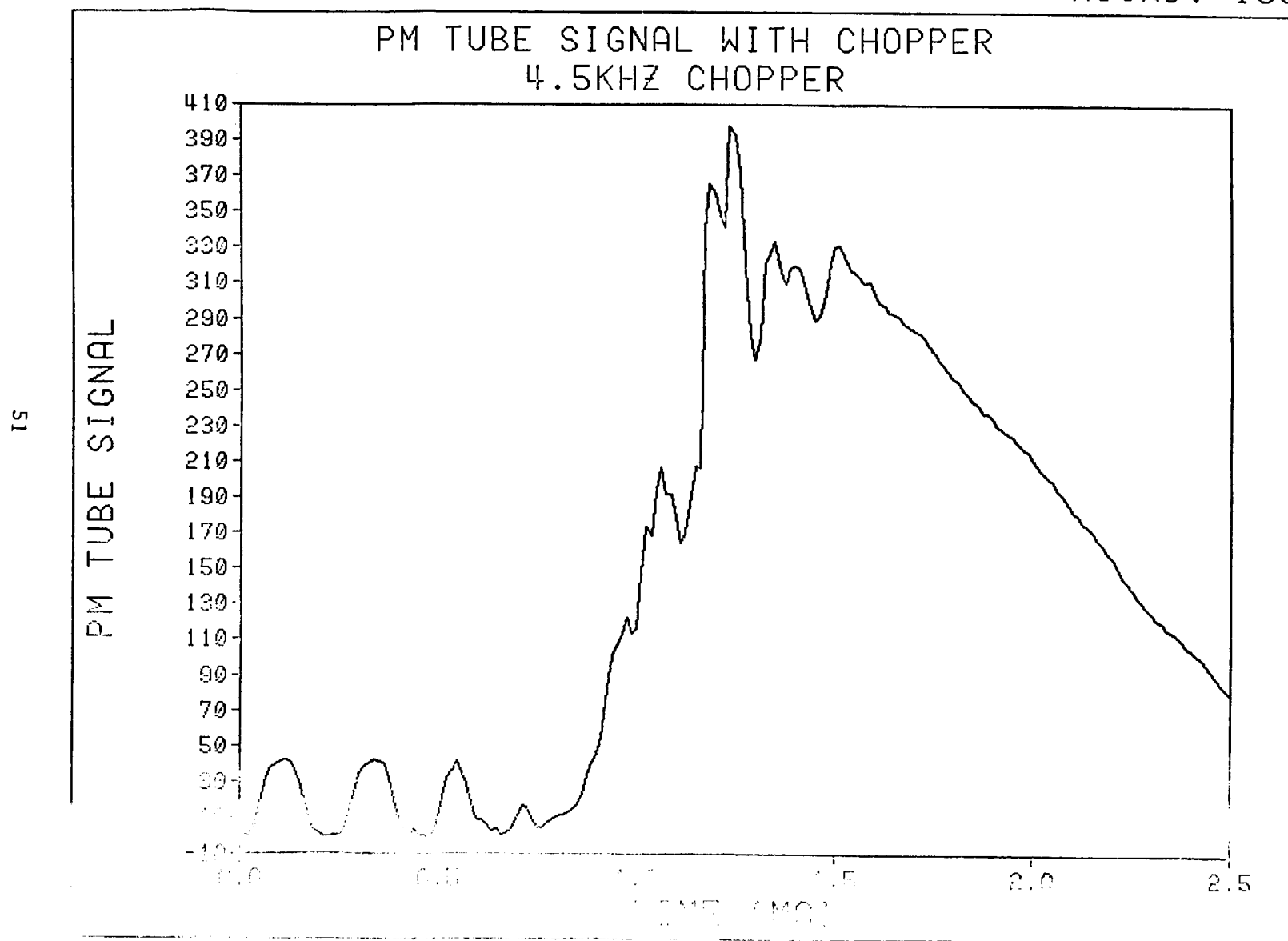


Figure D-3. Round 153 - Photomultiplier Tube Signal with Chopper, 4.5 kHz Chopper

APPENDIX E

EMISSION TIME DATA. TWO VOLUME METHOD

IGNITER FIRING

ROUND: 155

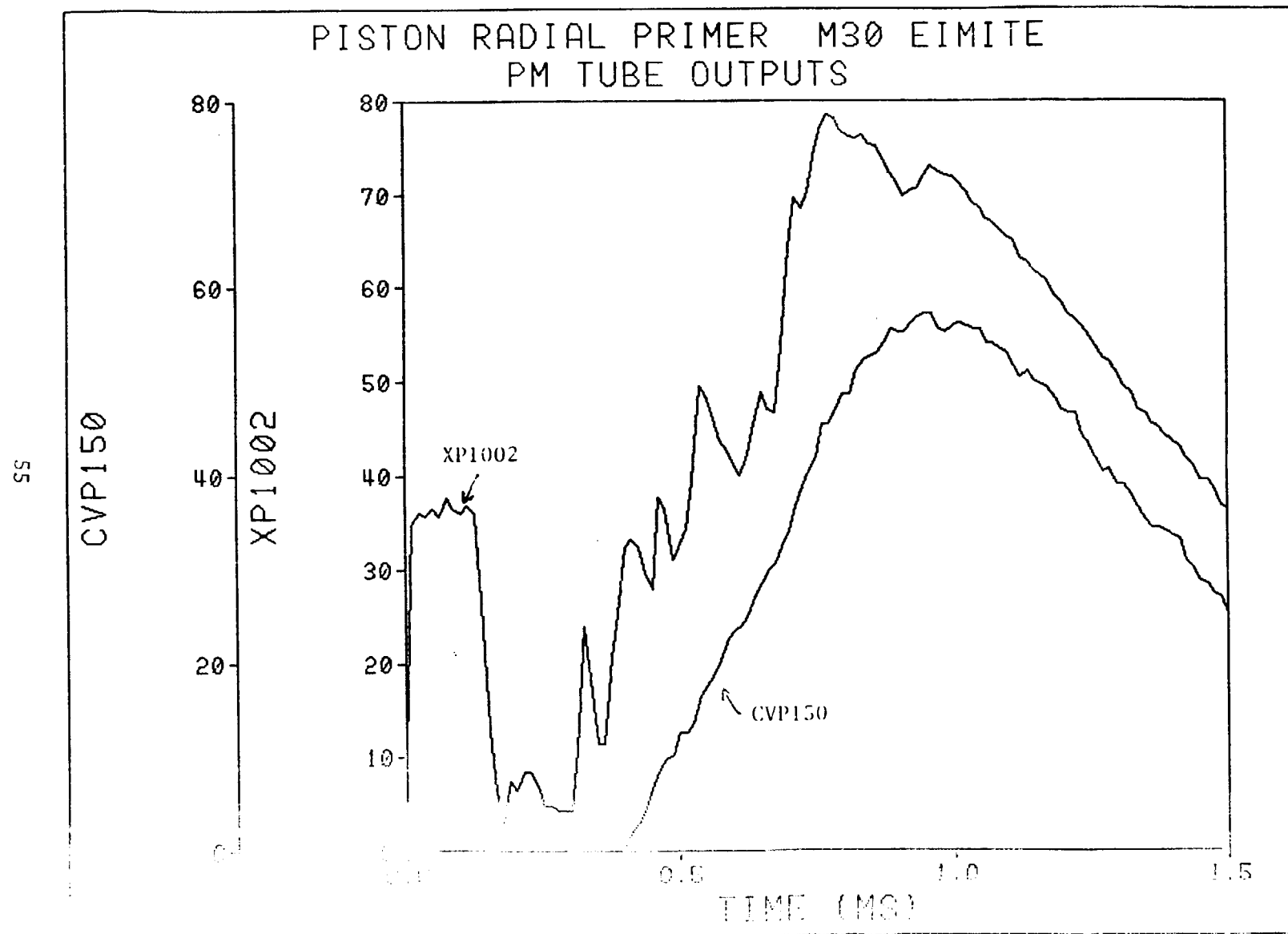


Figure E-1. Round 155 - M30 and Eimite, Photomultiplier Tube Outputs

IGNITER FIRING

ROUND: 162

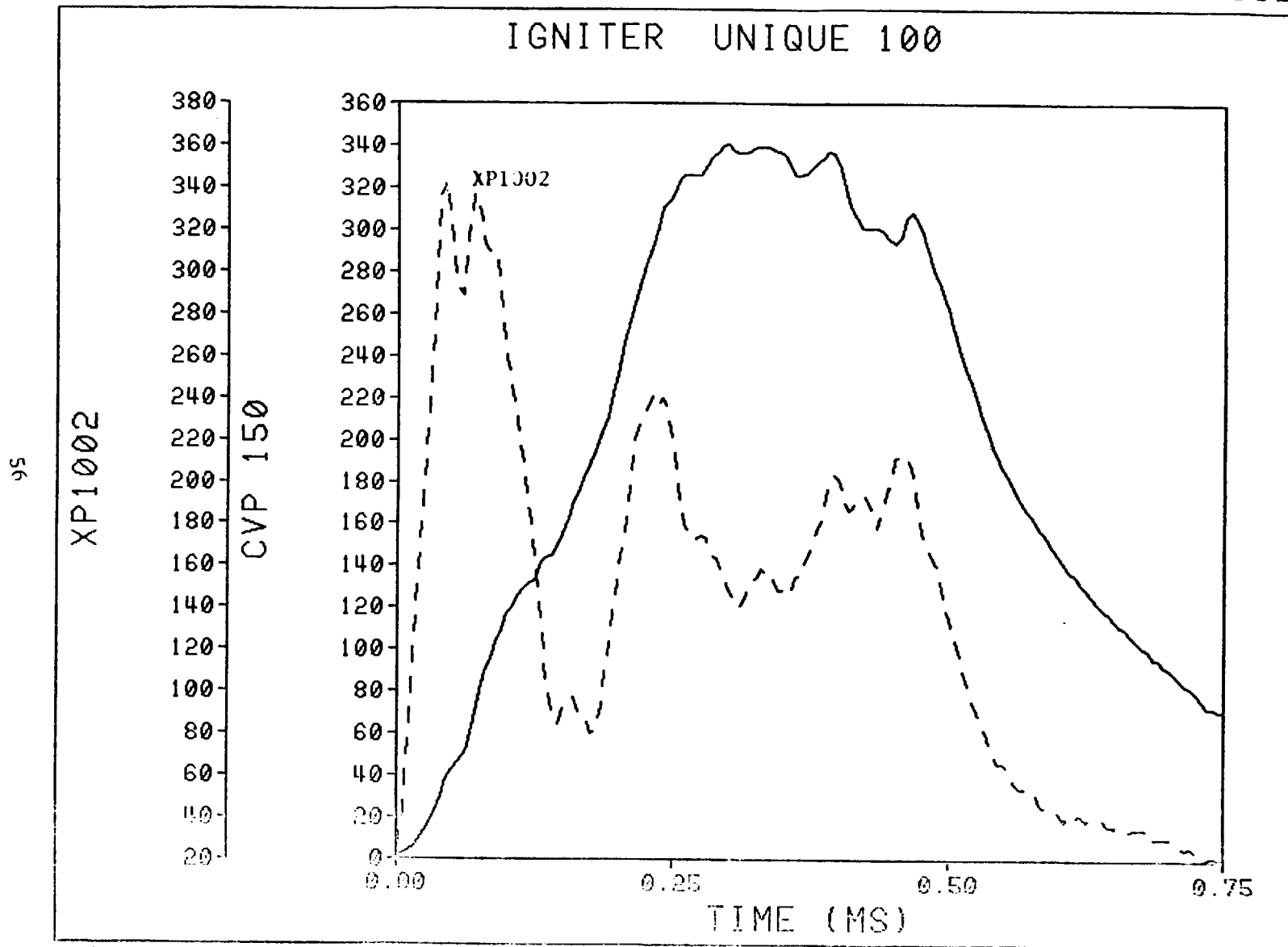


Figure E-2. Round 162 - Igniter Unique 100, Photomultiplier Tube Outputs

IGNITER FIRING

ROUND: 167

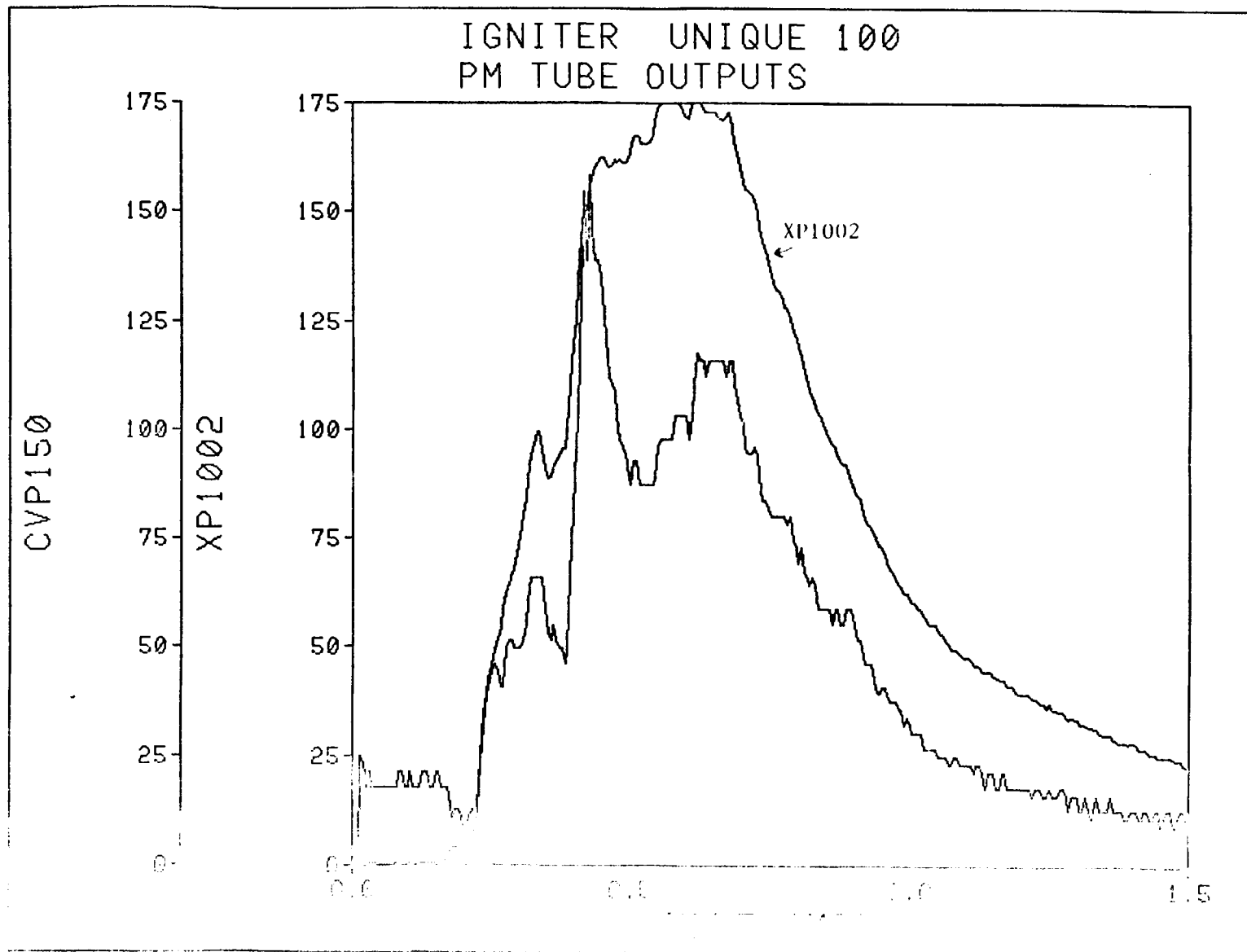


Figure E-3. Round 167 - Igniter Unique 100, Photomultiplier Tube Outputs

IGNITER FIRING

ROUND: 168

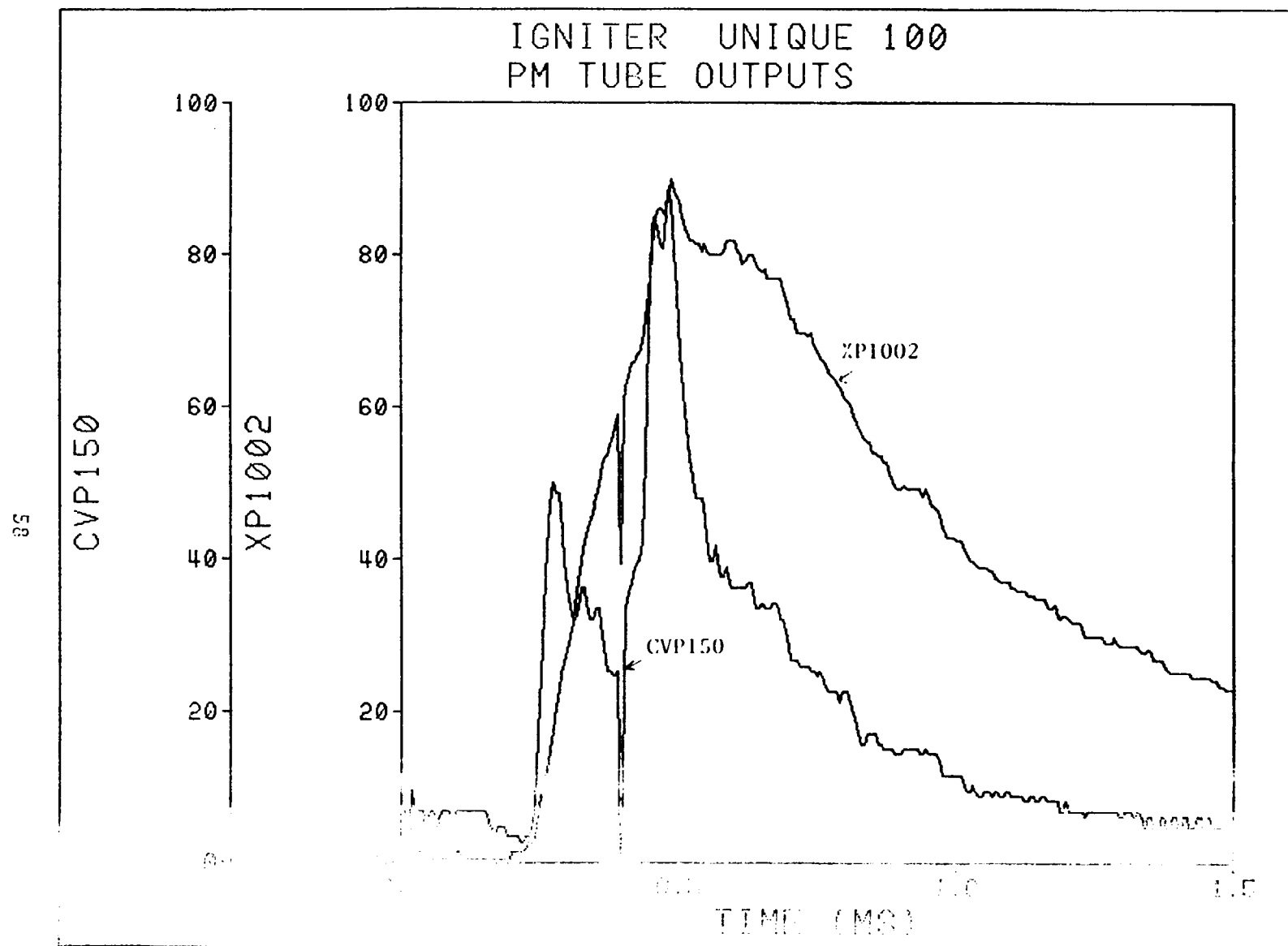


Figure E-4. Round 168 - Igniter Unique 100, Photomultiplier Tube Outputs

CLOSED CHAMBER

ROUND: 118 PLOT: 3

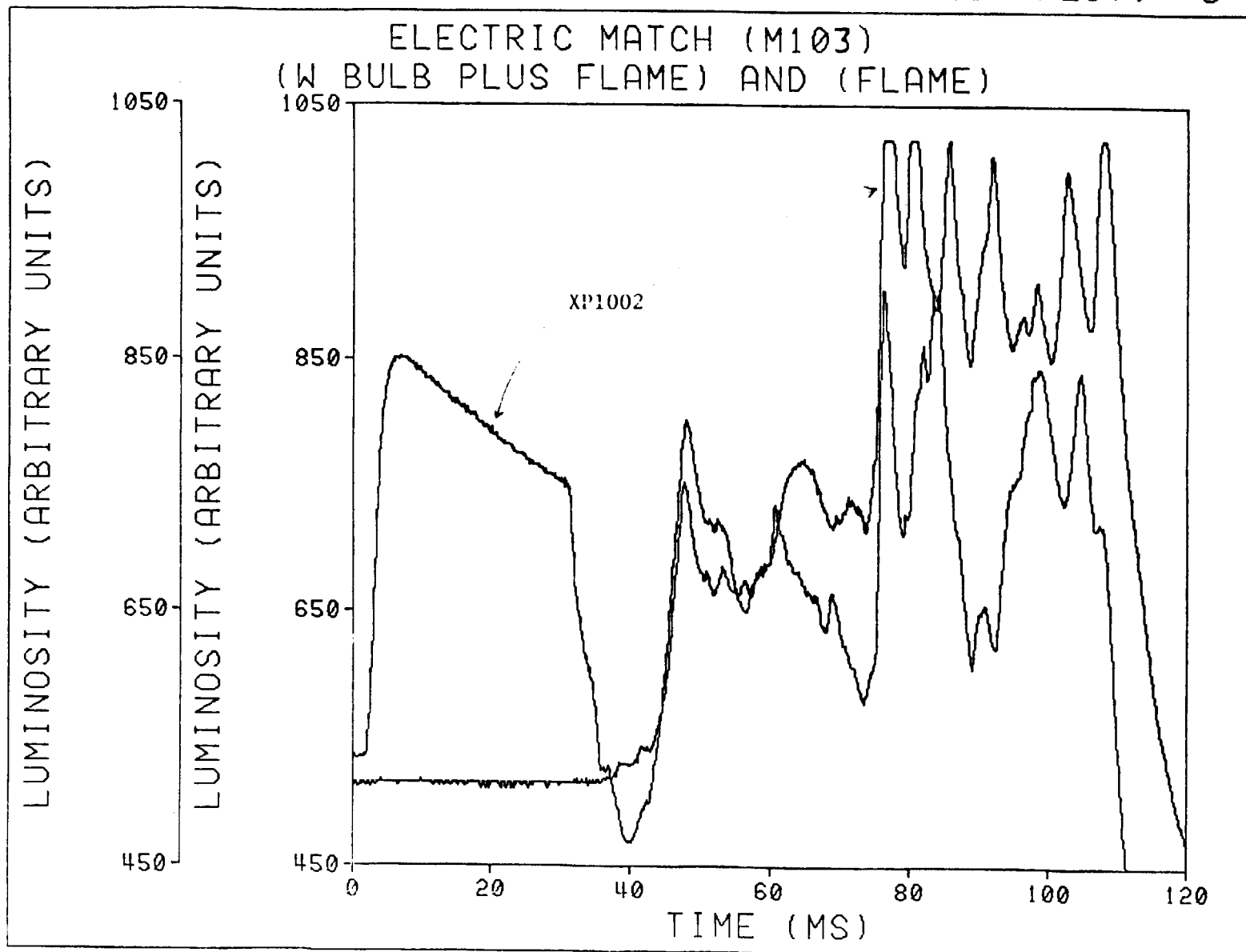


Figure E-5. Round 118 - Electric Match (M103), Photomultiplier Tube Outputs

APPENDIX F

TEMPERATURE TIME DATA. TWO VOLUME METHOD

IGNITER FIRING

ROUND: 155

63

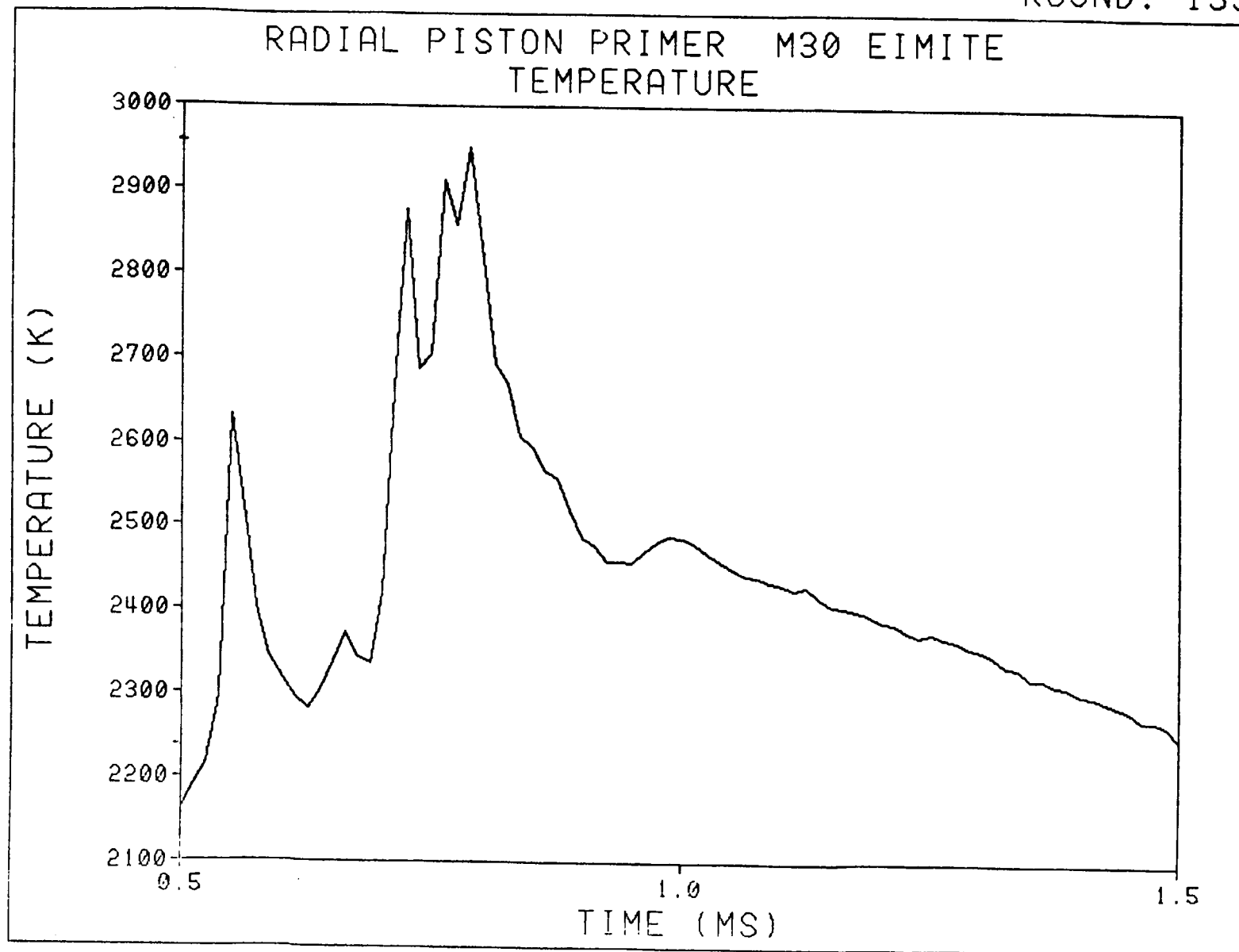


Figure F-1. Round 155 - M30 plus Eimite, Temperature vs Time

IGNITER FIRING

ROUND: 162

64

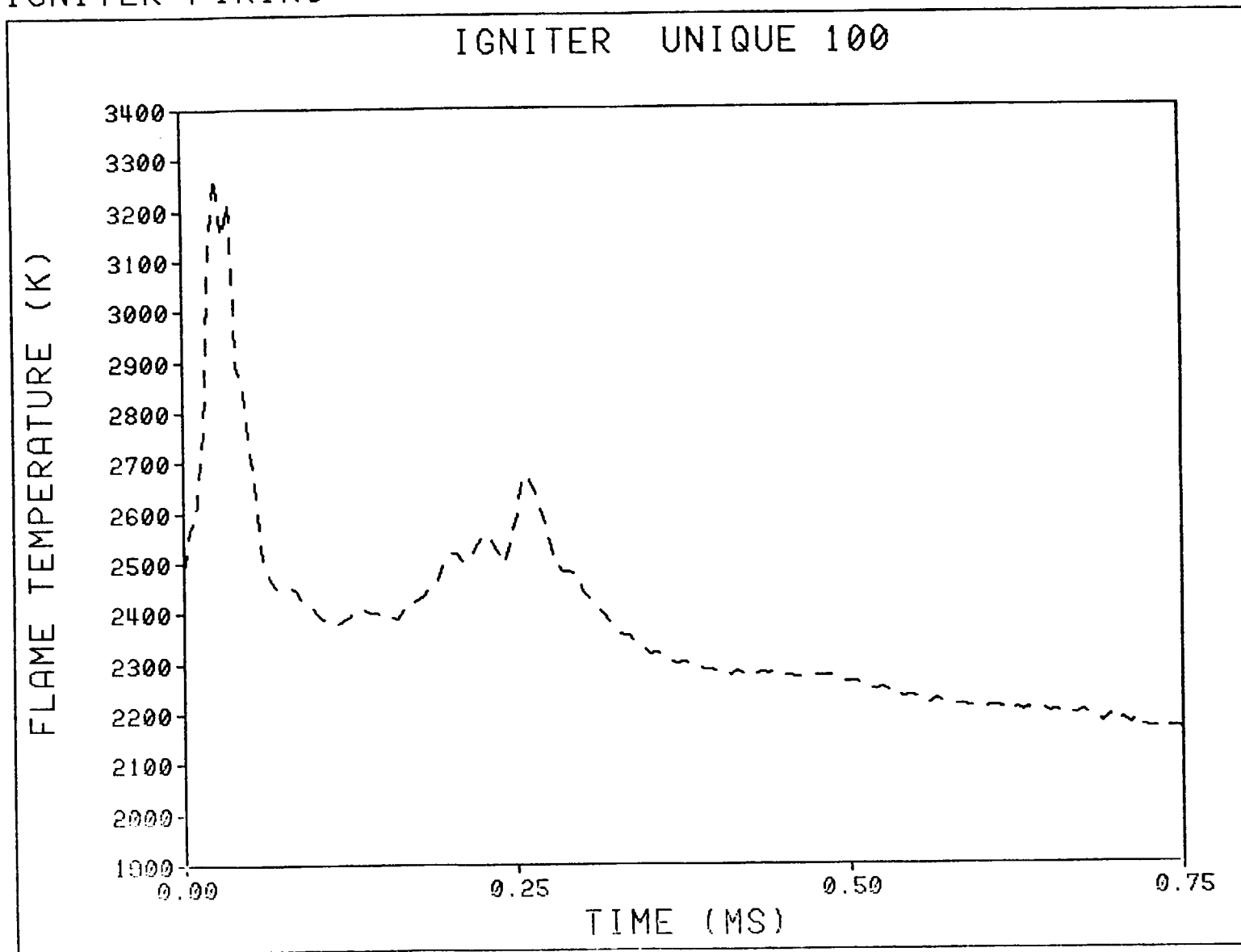


Figure F-2. Round 162 - Igniter Unique 100, Temperture vs Time

IGNITER FIRING

ROUND: 167

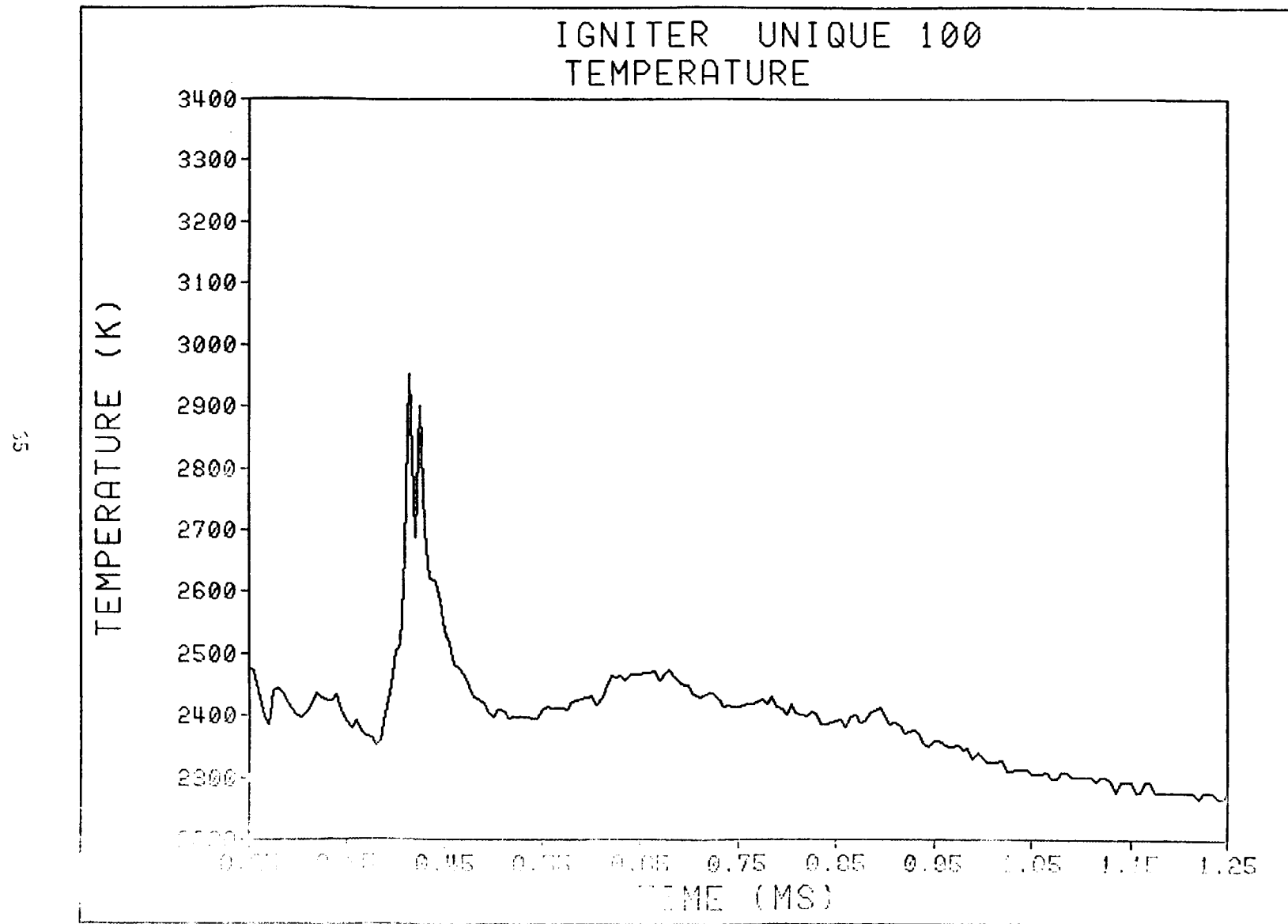


Figure F-3. Round 167 - Igniter Unique 100, Temperature vs Time

IGNITER FIRING

ROUND: 168

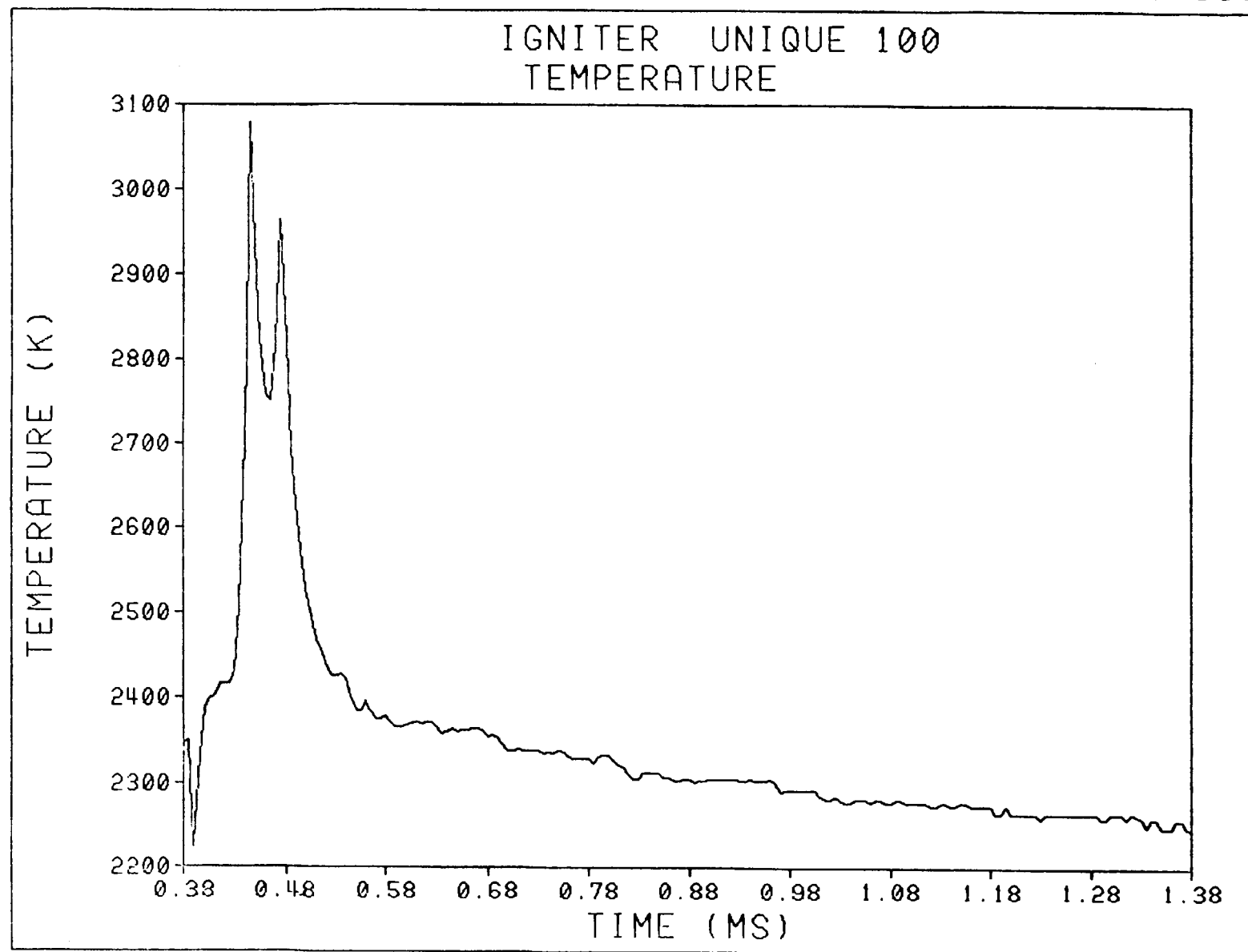


Figure F-4. Round 168 - Igniter Unique 100, Temperature vs Time

CLOSED CHAMBER

ROUND: 118

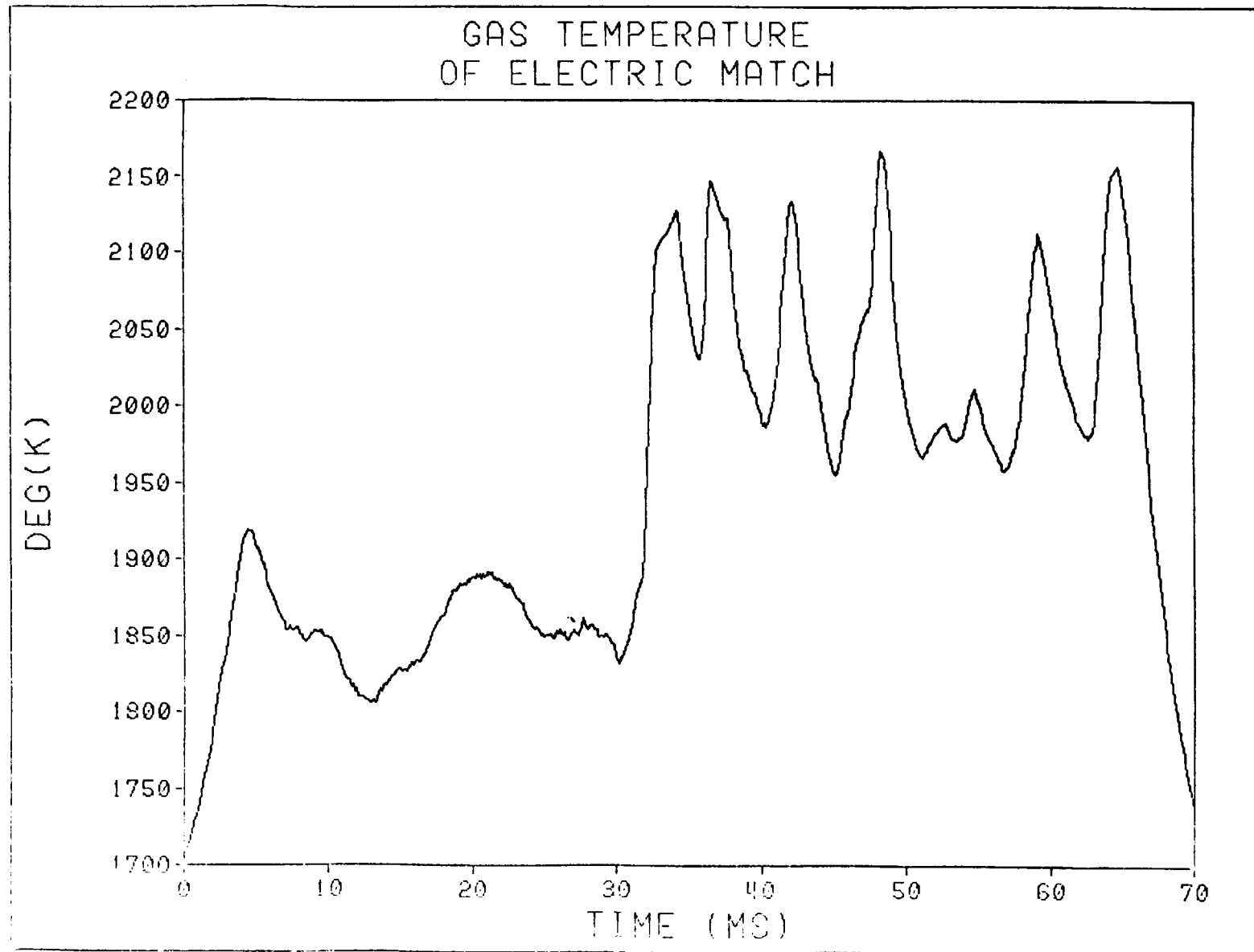


Figure F-5. Round 118 - Electric Match (M103), Temperature vs Time

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- A-1. Data Sheet 420, 5-70, Atlas Chemical Industries, Inc., Aerospace Components Division, Valley Forge, PA 19481.
- A-2. R. E. Bowman, Applied Physics Branch, BRL, 1980.
- A-3. Private communication from Bert Grollman, Ballistic Research Laboratory, June 76.
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- A-5. Private communication from E. Freedman, Ballistic Research Laboratory, Dec. 1981.
- C-1. F. Rossler, "Temperaturmessungen in Kurzzeitphysik," edited by Vollruth and Thomer, Springer, Wein (1967).
- C-2. J. deVos, "A New Determination of the Emissivity of Tungsten Ribbon," Physica 20, 690 (1954).
- C-3. G. Klingenberg, K. J. White and J. D. Knapton and W. F. Morrison, "Review of Spectroscopic Temperature Measurement Methods for Ballistic Applications," USARRADCOM Technical Report being reviewed (1981).

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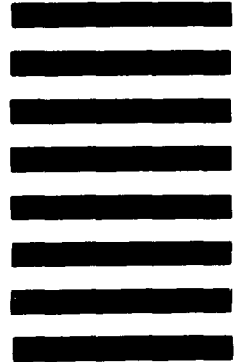


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